THE

ENGINEER SCHOOL

FORT HUMPHREYS, VA.

RIVER AND HARBOR IMPROVEMENT

SELECTED ARTICLES

JUNE 1923

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HARBORS ON LAKES ERIE AND ONTARIO

by

MAJOR DAN C. KINGMAN, Corps of Engineers. *

1904.

The title of this paper would apply to all harbors, whether natural or artificial, on both shores of Lakes Erie and Ontario, but it is intended to limit it to those harbors in the United States which are or have been under improvement by the General Government. It would be impossible to discuss in an intelligible way the progress which has been made in the last ten years in the improvement of harbors on these Lakes without first giving some consideration to the history of the harbors and the region which they serve; without offering some reasons why they were originally selected for improvement; and why the particular materials and methods which have been used for their betterment were selected. None of these harbors were originally planned to meet conditions at all comparable with those now existing. No one at that early time could have foreseen or imagined the enormous growth and development which has come to many of them, or the vast changes which have taken place in the means and methods of carrying on the commerce of the Lakes.

In 1820 the entire population of the eight States of the Union bordering upon the Lakes, that is to say, New York, Pennsylvania, Ohio, Indiana, Illinois, Michigan, Wisconsin and Minnesota, amounted to about 3,200,000. It now exceeds 32,000,000. In 1820 the entire population of the States of Ohio, Indiana, Illinois, Michigan, Wisconsin and Minnesota, amounted to less than 800,000. It is now more than 18,000,000, and the increase in wealth and material prosperity has been in a vastly greater ratio. In 1820 such commerce as existed upon the Lakes, was carried on by small sloops or other sailing vessels. It was insignificant in volume and only amounted to what was necessary to serve the needs of a sparsely settled agricultural region. In 1902 the commerce of the Lakes demanded the service of steel steamers 500 feet in length capable of carrying a cargo of 8,000 tons; and the receipts and shipments at the Lake Erie Harbors alone amounted to nearly 48,000,000 tons.

The Great Lakes of North America, penetrating far into the interior of a new continent, were early utilized as a pathway by explorers, for the purpose of trade with the aborigines, for war-

* Brig. Gen., Chief of Engineers, 1913-16.

like expeditions, later for the movement of settlers to the interior, and finally to serve the needs of a great inland commerce. The conquest and settlement of the continent spread from the Atlantic Coast toward the West, and for this reason Lake Ontario was the first of the chain of lakes to be utilized for purposes of navigation. At one time its trade exceeded that of all the other lakes combined, but as it is cut off from them by the Falls of Niagara its limit of usefulness was soon reached, and it is now of comparatively small importance for inland commerce. But when the obstacle of the Falls of Niagara is overcome by a canal of a capacity adequate to pass the largest vessels upon the Lakes with safety and promptness, Ontario will assume its rightful importance and will afford the eastern terminus for the Great Lake traffic.

In their natural condition these lakes offered very few safe and commodious harbors which were of sufficient depth to be used by vessels suitable for Lake navigation, and none at all which could be used by vessels of the present time. Shelter from storms and waves could be had within the mouths of the tributary streams, and sometimes in the bays or indentations of the shore line. These rivers and bays were generally deep enough for the small ships then in use, but their entrances from the lake were almost invariably obstructed or completely closed by bars, formed by the joint action of waves and currents, at or near the line of the lake shore.

During the season when storms were prevalent on the Lakes the waves washed up the sand and gravel, and almost completely closed the mouths of the streams, but during the time of the spring freshets the volumes of water discharged by these streams were generally sufficient to cut their way through the bars and afford and maintain for a time channels deep enough to permit the passage of the small craft which were likely to use them. The bars which separated the bays from the Lakes were generally more permanent in character than those at the mouths of rivers, and channels, more or less tortuous and uncertain, always existed across them, through which the water ebbed and flowed as was necessary to maintain the level between the bays and the Lakes.

All of these channels were constantly shifting, were of uncertain and varying depth and liable to be obliterated temporarily by the action of storms. Such as they were, however, they were of necessity made use of by the first comers. Explorers, traders and early settlers were too few in number, and their hold upon the country was too uncertain to permit them to undertake the permanent improvement of any harbor. It is told that when one of the first vessels came to Cleveland the crew had to be provided with shovels to dig a trench through the bar at the entrance to the Cuyahoga River through which they could draw their small vessel into the sheltered water within the river's mouth.

When the settlement of the region bordering upon the Lakes

had advanced so far that the population produced something in excess of its own requirements and found it necessary to transport its products to market by water, the need of better harbors became imperative. Between 1820 and 1830 the improvement of a large number of harbors on Lakes Erie and Ontario was planned, and the actual work of betterment was undertaken at several of them. Where the proposed harbor was within the mouth of a river the first effort toward improvement was directed to doing away with the river bar, and this was effected by the construction of jetties extending outward into the lake so as to prolong the natural banks of the river and to confine its discharge to a channel of moderate width. The result was invariably to secure a deeper and better entrance, and if the material was such that the current of the river could move it, the bar was completely washed away, and a channel secured and maintained between the jetties as wide and deep as the discharge of the river was capable of producing.

In the case of bays, in one or two instances, resort was had to dredging, but the dredging machinery of that early day was inefficient and the operation was tedious and expensive. In general, parallel jetties were constructed across the bar at or near the natural entrance, and the bar itself was protected by a similar structure built along its crest uniting the jetties with the shore. These "shore arms," as they were called, served to prevent other channels from cutting through the bar, and to confine the ebb and flow to a single well-defined entrance. The effect, of course, was to secure a better and deeper channel.

As the amount of money available for improving these harbors was small, it was necessary to construct such works as were required, of the cheapest material which would answer the purpose. Even if sufficient money had been available, it would have been impracticable at that time to procure skilled masons and quarrymen and the necessary machinery and appliances for the construction of stone jetties. The most available building material, therefore, was timber. The whole country was covered with forests, and logs could be had very cheaply and in unlimited quantity.

The portion of the jetties below the surface of the water was built of separate timber cribs. These were made of logs flattened upon two sides and notched together in the same way in which the houses or cabins of the time were built. The length of these cribs, which were of course rectangular in form, was that of a single log, 20 or 30 feet, and they were strengthened by a longitudinal wall, and one or two cross-walls, also built of logs. The logs were fastened together with wooden pins. The structures were floated into position, sunk upon the natural bottom of the lake, and filled with small stones gathered from the shores or from the fields. The cribs were sunk end to end along the line of the proposed jetty, and the superstructure was generally built of sawed timber and made continuous over a series of cribs. The side and cross-walls were generally 1 foot

thick and were carried up so as to give the jetty a height of 6 or 7 feet above the ordinary level of the lake. The superstructure was then filled with small stone and the whole was planked over to form a deck.

These structures possessed considerable strength, and as long as the timber of the superstructure was sound they could withstand the forces to which they were exposed. Unpainted and unprotected timber, however, decayed rapidly and the life of an ordinary superstructure was from 12 to 15 years. At the end of this time it required a complete renewal. As the work progressed the cribs were built of sawed timber in place of hewed logs, and iron drift-bolts were substituted for wooden pins. The submerged portion of the structure was not subject to decay, but as the cribs were not tight and were filled with loose stone, the water rose and fell inside of them as the waves came against them; and as this water in time of storms was filled with sand it scoured out and enlarged the openings particularly at the joints. The cribs were not built with tight bottoms, hence the stone escaped from them if the channel scoured out close enough to undercut them. This left them unsupported and occasionally was the cause of breaches being made through the jetties. In deeper water where the cribs were high, there was another cause of injury. The repeated shocks due to waves caused the small stone filling to exert a wedge-like action which spread the cribs apart at the corners.

In the later works the cribs have been made stronger by using vertical posts at the corners and cross-walls, and by bolting the structure together with strong screw-bolts. Tie-rods have also been used to prevent the walls from spreading, and within the last few years many of the cribs have been protected by sheathing them with hard wood plank 3 or 4 inches in thickness, placed vertically so as to protect the softer wood of the crib walls, and to afford it additional support and strength. This sheathing covers the openings so well that but little water flows in and out of the cribs. It also protects them from wear of ice and other floating bodies. The modern cribs have been made very much longer than those first used, some of them being more than 200 feet in length.

Such were the reasons which led to the selection of certain harbors on Lakes Erie and Ontario for improvement, and such were the reasons that determined the choice of the particular materials and methods that were employed to secure improvement desired. As the population of the States bordering upon the Lakes increased, and the industries became more diversified, there was a rapid increase in the Lake commerce. This led to competition and the necessity for a reduction of freight rates, and, hence, to the use of a larger class of vessels. Larger vessels required deeper entrances to harbors, as the natural currents of the small streams and bays were seldom sufficient to secure or maintain of themselves a greater depth than 8 or 10 feet. Therefore, it became necessary to resort to dredging.

WEST BREAKWATER, CLEVELAND HARBOR, SHOWING TIMBER SUPERSTRUCTURE IN A STATE OF DECAY, BEFORE IT WAS RENEWED IN CONCRETE.

WEST BREAKWATER, CLEVELAND HARBOR, SHOWING THE PARAPET AND BANQUETTE OF THE CONCRETE SUPERSTRUCTURE.

An Act of Congress as early as July, 1836, made an appropriation for a dredging machine for use on Lake Erie. As the amount appropriated was only $8,000, the dredge must have been a small affair. In 1852 three steam dredges were authorized for Lakes Erie, Ontario and Michigan, respectively, at a cost of $20,000 each, including the equipment and the dump scows, or discharging scows, as they were called in the Act. This made it possible for the United States to do a portion of the dredging with its own machinery, but by far the greater part has been done by contract with private individuals or companies who furnished their own plant. A depth of 8 or 10 feet was sufficient for the earlier commerce of the Lakes. This, however, was soon increased to 12, then to 16, and now a minimum of 21 feet is required for all harbors used by the larger class of vessels.

The jetties, therefore, have long since lost their primitive function, which was an active one, namely, to scour out a channel by the natural force of the currents, and have become simply conservative in their nature, their office being to protect the artificial channels which have been secured and are now maintained my dredging. In the original designs the jetties were of necessity placed close together in order to confine the currents and wash away the bars, and as the streams were small, the distance between the jetties was from 120 to 250 feet, seldom exceeding the latter width. This made a very narrow entrance for a vessel to attain, particularly when driven toward the shore by a strong wind, and if it failed to make the entrance it was very apt to be wrecked on the beach.

In some of the earlier improvements the jetties were made flaring at the outer ends so as to give a funnel-shaped entrance and afford a wider opening for the convenience of vessels. No doubt, it had this effect, but it also afforded a wider opening for the entrance of waves, and caused the incoming wave to be heaped up at the gorge or narrowest portion and created at certain times a rough and dangerous channel; so that this style of construction was soon abandoned and the parallel jetties used instead. There was, therefore, great need at this time for harbors of refuge which could be entered with greater ease than these jettied channels, and where vessels could ride out a storm in safety and enter the commercial harbor when favorable conditions were resumed. This led to the planning of breakwaters for the most important harbors on the Lakes, that is to say, for Oswego on Lake Ontario, and Buffalo and Cleveland on Lake Erie.

The same reasons which caused the adoption of timber cribs filled with stone for jetty construction determined their use in the construction of the earlier breakwaters. The under-water portion of the breakwaters was generally built of timber cribs from 30 to 35 feet square, divided into compartments by transverse and longitudinal walls, these cribs being sunk side by side along the line of the proposed breakwater. As in the case of the

jetties they were filled with small stone, the superstructures were of timber and were continuous over a great many cribs, and generally continuous throughout the entire length of the breakwater. In the earlier forms the superstructure was simply carried up to a height of about 7 or 8 feet above the Lake level and then decked over, but as the heavy seas came over them very freely so that a vessel could not lie alongside, the form was changed so as to make the outer part, or parapet, about 12 feet high and the inner part, or banquette, about 5 feet. This gave a greater protection without increasing the quantity of material required for construction.

The same trouble was had with decaying superstructures and with damaged cribs due to sand and ice erosion and to the wedge-like action of the small stone filling.

The high vertical face which this style of breakwater presents to the lake, throws back the incoming sea in such a way that the reflected wave is superposed upon the advancing one in a manner to produce a very rough and irregular motion of the water surface, and this effect is extended to a considerable distance. Masters of vessels say that they can tell at night when they are passing opposite the harbors of Cleveland or Oswego, several miles out in the lake, by the peculiar broken and disturbed seas which they encounter. This would indicate that the breakwater itself must be subject to very severe shocks, and indeed there is an abundance of evidence of a much more direct character that such is the case. The structures are racked and frequently suffer serious injuries from the force of the waves alone. To protect them from this action it has been proposed recently to deposit against them, on the exposed side, a mound of heavy rip-rap with a general surface slope of 1 on 2, and extending upward nearly to the top of the superstructure. Above the surface of the water, and for several feet below it, this large stone will be placed in the form of a rough pavement.

To meet the difficulty experienced by vessels in making the narrow entrance between the jetties at certain of the harbors, a plan has been devised for constructing two detached breakwaters converging toward the lake and having an opening between their outer extremities two or three times as great as the opening between the jetties, the entrance being placed on the prolongation of the axis of the channel and 1,000 or 1,500 feet from the outer end of the jetties; and the gorge line of the breakwater to be situated at about the outer end of the jetties. This gives to the detached sections of breakwater a length of 1,500 or 2,000 feet each, the angle which they make with the axis of the channel being varied from 30 to 45° as may be necessary to afford the maximum protection. Such works have been planned, and in part constructed, for the harbors of Lorain, Fairport, Ashtabula and Conneaut, on Lake Erie. They will, when completed, give a much wider and safer entrance for the vessels, will permit them to enter, if necessary, at an angle with the axis, and give them space enough to straighten up before en-

BUILDING TIMBER CRIB FOR BREAKWATER CONSTRUCTION, SHOWING THE MANNER OF FRAMING AND FASTENING.

CLEVELAND HARBOR, OHIO. BUILDING A TIMBER BREAKWATER WITH SLOPING FRONT.

tering the narrow channel; and because the breakwaters diverge toward the shore they will give the waves coming through the entrance an opportunity to spread out and die down so as to leave an area of smooth water near the entrance to the jetties.

The great disadvantage of timber structures is the perishable nature of material when not entirely submerged. There is another disadvantage due to the continued increase in the cost of suitable timber, thus depriving them of the advantage of cheapness, which they originally possessed in a pre-eminent degree. The ordinary life of a timber superstructure is from 12 to 18 years, depending in part upon its exposure to the waves, and in part upon the excellence of the material of which it was originally constructed. On an average they should be renewed completely every fifteen years. The stone filling, of course, is available for the new structure, but the cost of rehandling it is almost as much as it is worth. To rebuild a timber superstructure costs about 30% of the original price of the entire structure. This means an annual fixed charge of 2% for maintenance of works of this character, not including extraordinary expenditures resulting from unusual accidents or injuries. This is a very heavy charge. It has been recognized from the first, and in the construction of the first breakwater at Oswego on Lake Ontario an attempt was made to build the superstructure of cut stone laid in cement and doweled together. However, the foundation afforded by the comparatively flexible timber cribs which yielded readily to the shock of waves, was so poor and so unsuited to carry a cut-stone masonry structure that the latter was soon shaken to pieces. Recently, concrete has been used extensively for the above-water portion of these works.

The timber-crib breakwaters at Cleveland and at Buffalo are now to a large extent equipped with concrete tops. The form given has generally been about the same as that adopted where timber was used, that is to say, in the case of breakwaters there has been a parapet and a banquette.

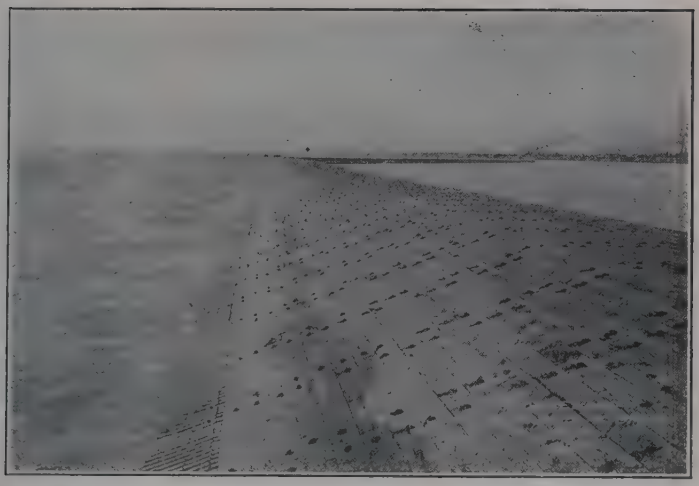
In preparing the cribs for a concrete top they are generally cut off at a depth of about 3 feet below the mean level of the water surface(or well below the line above which the timber is subject to decay. Concrete blocks about 4 feet wide, 4 feet high, and 8 feet long, or such other length as may be determined by the distance between the cross-walls, are prepared and placed upon top of the walls of the crib. Other blocks, if necessary, of lesser width are placed upon the center walls and cross-walls. The small stone filling is then carried up to within a few inches of the top of the blocks, and upon this surface the mass concrete is moulded in place. The blocks of mass concrete are generally from 20 to 30 feet in length, the width being the full width of the crib. The blocks are separated from each other by a double layer of tarred paper.

In the Cleveland breakwater the mass concrete of the banquette is 5 feet thick, the parapet 5 feet high, and the blocks are alternately 20 and 30 feet in length. The weight of a

block is from 300 to 450 tons, approximately, according to its length. They are built in such a way as to break joints with the cribs, most of which were 50 feet long, and their mass and weight is largely relied upon to keep them in place. Notwithstanding their weight and the manner in which they are placed, they do work against and chafe each other during storms, due to the yielding of the crib substructure. It will probably be necessary to protect the whole with rip-rap on the lake side in the manner already described.

A few years ago a modification was made in the form of timber superstructure used in the extension of the east breakwater at Cleveland Harbor. It was carried up vertically for only 2 feet above water level, then it was inclined at an angle of 1 on 2.5 until it attained a height of 10 feet above the water surface. From that point it was horizontal until it met the harbor face which was vertical. All decking was of 12-inch timber throughout instead of plank, and the angle or knuckle near the water was protected from erosion and injury by iron straps 4 feet long, 4 inches wide, and 0.5 inch thick, which were bolted vertically so as to cover the angle. It was considered that the protection in this form would stay on better and was not liable to such extensive injuries as an equivalent protection of iron plates. In observing this structure during storms, it is seen that the waves slide easily up the inclined surface and spill over the back of the structure into the harbor. The extensive reflex wave so noticeable in the vertical form is hardly perceptible in this case. The shock to the breakwater is evidently much less and the pressure which comes upon it is downward, and the resultant probably falls inside of the base. This form of superstructure which is so satisfactory in the case of timber is now being adopted where concrete is used on breakwaters. In the case of jetties the manner of building the concrete superstructure is similar, and the form is either the ordinary form used with the timber, or else with the gentle slope on the exposed side as in the case of breakwaters.

The first radical change in the materials and methods of breakwater and jetty construction on Lakes Erie and Ontario was suggested in 1895. A Board of Engineer Officers was appointed at that time to consider certain necessary improvements to the harbor of Buffalo. It was proposed to extend the breakwater about 12,000 feet so as to afford a much larger sheltered area for the convenience of vessels and the protection of wharves. The Board recommended a rubble-mound breakwater similar in construction to a number of stone breakwaters which had been successfully built on the Atlantic Coast. It was proposed to build up first a mound of small stone to a height of about 12 feet below the mean lake level, and upon this to build, with large stone from 4 to 10 tons in weight, up to a height of about 10 feet above that level. The large stones were to be deposited along the axial line of the proposed structure, with side slopes as steep as the material would naturally assume. It was ex-



CLEVELAND HARBOR. A PORTION OF THE EAST BREAKWATER, SHOWING THE SUPERSTRUCTURE BUILT WITH A GENTLE SLOPE ON THE EXPOSED SIDE, UP WHICH THE WAVES CAN SLIDE WITHOUT SHOCK.

HARBOR OF FAIRPORT, OHIO, LOOKING OUTWARD TOWARD THE LAKE FROM THE OUTER END OF THE JETTIES, SHOWING VESSELS IN THE ICE-DAM WHICH RESULTED FROM THE FLOOD OF 1904.

pected that the action of storm waves would reduce the height and flatten the slopes to a position of ultimate stability. It was recognized that the structure would have to be recapped, probably more than once, with large stone until it remained permanently at a height of about 10 feet above the water at ordinary lake level. The advantages claimed for a breakwater of this kind were: That nothing placed in it was lost; that no conceivable injury to it could do more than reduce its height somewhat; that it must always be left in the best possible condition for repairs; and that a time must certainly come when repairs of any kind would cease to be necessary.

When the breakwater was constructed the recommendations of the Board were not fully carried out, but under proper authority a number of modifications were made. The core, or heart, for reasons of economy, was made of coarse gravel which was carried up to a height of about 10 feet below the water surface. This core was covered with a heavy thick layer of stone of quarry-run sizes, that is to say, of the irregular sizes and shapes that could be most cheaply and readily obtained from the quarry. It was of large and small stone mixed together. From a point 15 feet below the water surface on the lake side a paving of heavy blocks of stone was carried up over the structure, and down on the harbor side to a level 10 feet below the water surface. To this portion of the structure a regular and uniform profile was given and the pavement made the slopes smooth and even, and the structure presented a fine appearance. From 15 feet below water on the lake side up to 3 feet above, the pavement was given a slope of 1 on 2.5; thence upward to the top it had a slope of 1 on 1.22. The top was horizontal and 14 feet wide, and 12 feet above the ordinary lake level. On the harbor side the slope of the pavement was 1 on 0.7.

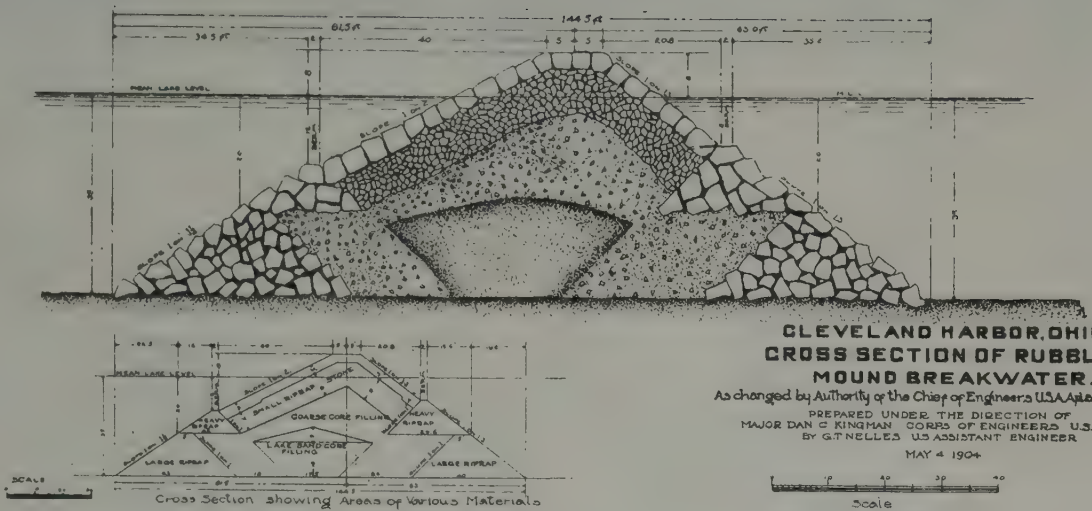
A rubble-mound breakwater has been adopted for the proposed improvement of the harbor of Cleveland, Ohio, which will involve the construction of nearly 20,000 linear feet of this structure. Rubble mounds are also used for the detached breakwaters at Ashtabula, and Lorain. The cross-section of the Cleveland breakwater differs somewhat from that of Buffalo. In the construction parallel ridges of large stone are first placed at a proper distance apart to outline the base of the structure. They are carried up to a height 20 feet below the water surface. Their inner slopes are then covered with a very thick layer of shale, coarse gravel, or furnace slag, and the space between these slopes is filled with a core of lake sand. A second set of ridges conforming to the slopes is then built of very heavy stone, and the core is carried up to the proper height. Upon this a thickness of about 9 feet of small stone is placed, and this in turn is covered by a smooth pavement of heavy blocks about 3 or 4 feet thick. The pavement extends from 12 feet below water on the lake side to 8 feet below on the harbor side. In the profile the slopes are as follows: On the harbor side a uniform slope of 1 on 1.3; on the lake side from the superior crest down to a depth

of 12 feet a uniform slope of 1 on 2; thence to the bottom a slope of 1 on 1.5.

At Ashtabula and in the west breakwater at Lorain the construction will be similar, but as the structures are in shallower water the sand core is not used. The pavement presents a smooth surface and, therefore, a fine appearance, and as the stones which compose it are large and carefully placed they are not at all likely to be moved or disturbed by waves or ice. The style of construction, however, has this disadvantage that if the pavement is broken the injury is likely to be wide spread, and if the structure settles irregularly and unequally it is more difficult to bring it back to grade than in the case of a simple rubble mound.

The most recent design for a rubble-mound breakwater is that which has just been approved for the east breakwater at Lorain. This has a core of shale, a covering of quarry-run stone, and from a depth of 12 feet below the surface, a covering 12 feet thick of large blocks of stone from 8 to 12 tons in weight. These stones are simply deposited in place and are not laid as a pavement. More care is taken to bed and bond them than to make them conform to any particular cross-section. It is believed that this will prove the cheapest form of rubble-mound construction that has yet been tried.

As long as the jetties were parallel and close together it is evident that a rubble-mound construction would have been open to many objections. Pieces of stone might wash down into the channel and vessels might be injured by striking them or by striking against the rough and irregular slopes. But now that jetties are no longer used as active works to secure and maintain channels, but have for their office simply to protect channels which have been deepened by dredging, there is no longer any necessity for keeping the jetties parallel or for building them close to the sides of the cut. It is possible, therefore, to give them almost any position which will break up the waves and prevent material from being washed into the channel. In a new jetty recently planned for improving the harbor at Huron, Ohio, it was proposed to use a rubble-mound jetty terminating at its outer extremity in a timber-crib pier head with a concrete superstructure placed at a proper distance from the west jetty to afford the desired width of entrance. From the pier head the jetty extends toward the shore, diverging from the channel so as to finally reach the shore 1,000 feet or more from the other jetty. It is believed that this will fulfill every purpose required of it, and at the same time will shelter a considerable length of lake shore; and that it may be built upon the natural bottom of the lake provided no dredging is allowed nearer the toe of the slope on the harbor side than ten times the depth to which it is proposed to dig. The cross-section of this jetty has a very simple form. The structure has a core of small stone, shale or sand, and is built up in the main of large blocks


MEAN LAKE LEVEL
SMALL RIPRAP
COARSE CORE FILLING
HEAVY RIPRAP
LAKE BOTTOM CORE FILLING
LARGE RIPRAP
SCALE
Cross Section showing Areas of Various Materials
CLEVELAND HARBOR, OHIO.
CROSS SECTION OF RUBBLE MOUND BREAKWATER.
As changed by Authority of the Chief of Engineers U.S.A. April 1904.
PREPARED UNDER THE DIRECTION OF
MAJOR DAN C. KINGMAN CORPS OF ENGINEERS U.S.A.
BY G.T. NELLES U.S. ASSISTANT ENGINEER
MAY 4 1904
Scale

of heavy rip-rap without any effort to present a smooth surface or to conform strictly to a fixed profile.

Now that materials which are not subject to decay have been adopted for jetty and breakwater construction, and a style and method of construction which produce structures strong enough to resist the forces to which they are exposed are used, it follows that all work of this character proposed for the improvement of harbors on these lakes will finally be completed, and that thereafter it will only be necessary to maintain the improvement which has been secured. It is evident that the things of real value to navigation are the artificially deepened channels and areas. All the other works are simply designed to protect or shelter them, and, as the protection and shelter cannot be made perfect, dredging will continue to be necessary at all of the harbors.

The type of dredge heretofore used on the Lakes has been the "dipper" dredge, which has gradually developed from a crude affair, operated by the power of a single horse, to a machine which can handle a dipper of 8 or 10 cubic yards capacity. The dipper dredge is as nearly a universal machine as any that could be devised. It can excavate anything from soft rock to mud or sand, but it is an unseaworthy style of craft and is dangerous to take out a long distance in the lake. Moreover, from its method of operation it cannot dig when the water is rough, and hence a great deal of time is lost to these dredges when they are required to work in an exposed locality.

The United States is now building a special dredge for use on Lake Erie. It is of the sea-going suction type. Its capacity should far exceed that of the best dipper dredge, and its construction will enable it to work in exposed localities at all times except during violent storms. Great economy and convenience will undoubtedly result from its use.

The harbor of Toledo, on Lake Erie, is an exception to the ordinary jettied harbors. It is within the mouth of the Maumee River, and the improvement is effected solely by dredging. No jetties, breakwaters, or similar works are resorted to.

The plan of improvement which is now in course of execution provides for the excavation of a channel 400 feet wide and 21 feet deep through Maumee River and Bay. The total length of this channel is about 15 miles, of which 8 miles are in the bay and 7 miles within the mouth of the river, and the work will require the removal of 8,000,000 cubic yards of material. The channel in the bay is excavated in a perfectly straight line from the mouth of the river to the 21-foot contour in the lake. The natural depth of the bay, for a greater portion of this distance, is 10 feet or less. The material in which the cut is made is a moderately stiff clay. The observations made upon the unfinished work indicate that a considerable amount of dredging will be necessary to maintain the channel. It seems probable that the average annual amount will not be less than 300,000 cubic yards; but the removal of this quantity of silt with a suitable

dredge will cost very much less than the annual interest upon cost of parallel jetties of this length.

It must be admitted that a small river or creek does not and cannot furnish the most favorable location for the development of a large commercial harbor. The ground bordering the stream is often unfavorable for supporting heavy structures. The valley of the stream is apt to be narrow and contracted, and the stream itself, while it may prove of some assistance at the outset, is a weak ally, and in the end, a source of danger and expense. The periodical freshets which occur in it, the ice gorges which occasionally form in a cold climate, and the large amount of silt which it annually discharges, are sources of difficulty and danger which lavish expenditure may mitigate but cannot abolish. It is believed, if it were now a question of selecting a site upon the shore of either of these lakes for a great harbor where a large city should be built and an extensive commerce developed, that the mouths of creeks and rivers should be carefully avoided. It would be best to select a point upon the straight shore of the lake where the bank was not too high, where the foundation was good, and where deep water comes in near to the shore. There, a strong and durable breakwater should be built inclosing an ample area and provided with safe entrances and exits. Under the shelter of this structure, wharves should be constructed and railway tracks should lead to them directly from the interior. Such an arrangement would lend itself best to an extensive commerce and would be susceptible of development and expansion to conform to the growth of trade.

The harbors of Lorain, Cleveland and Fairport, are all at the mouths of small rivers, and observations have been made covering a considerable period of time to determine the regimen of these streams. The areas of the drainage basins of the streams amount to 550, 972 and 759 square miles, respectively. The mean annual discharge of the three streams is 648, 1,345 and 1,237 cubic feet per second. The discharge from day to day is subject to wide variation, the flood being ten or twelve times as great as the mean.

Daily sediment observations upon these three streams covering a period of about a year, during which no abnormal conditions occurred, indicated that the Black River brought down annually 106,000 yards of sediment, the Cuyahoga River, 193,000 yards, and the Grand River, 157,000 yards. These are large amounts of material to be deposited in artifically deepened areas or in a shallow lake near the entrances of harbors. It may be stated, however, that while this annual tribute must have an important effect in time, its effect from year to year is less than one would suppose. Nine-tenths of the amount of silt is discharged during perhaps half a dozen freshets each one of but 2 or 3 days' duration, and during these freshets the velocity of water is sufficient to cause a strong current to be directed far out into the lake. The exact course pursued by

this current after it leaves the jetties is determined or materially modified by the accidental direction and force of the shore currents at the time. Hence, the greater part of the material is scattered over a wide area.

It is worthy of note that in the case of these three rivers, during the year that they were under observation, the quantity of sediment discharged seemed to be a constant per square mile of territory in the drainage basin, amounting in each case to about 200 cubic yards per square mile. It is recognized that this may be a mere coincidence and that it certainly would be materially modified in a year of abnormal freshets, but if it indicates an average which holds good throughout the Erie water-shed of the State of Ohio, then this State alone delivers an annual tribute of 2,500,000 cubic yards of silt to Lake Erie, and nine-tenths of this quantity enters the lake through the mouths of creeks which have been improved as harbors.

If freshets occur when the streams are covered with ice, conditions arise which are dangerous and destructive, not only to wharves and shipping, but to the dredged channels and areas as well.

The first half of the winter of 1903-04 was very cold, and the ice upon the bays and rivers became 18 inches or 2 feet in thickness. It even formed on Lake Erie itself along the shore, extending outward as far as the eye could reach. The ice in the lake was repeatedly broken up by waves as it formed, and the ice floes were forced under each other until the whole became exceedingly thick and solid.

In the latter part of January the weather suddenly moderated. The temperature rose to a point 15 or 20° above freezing. At the same time a copious warm rain set in. The water-shed was covered with deep snow which was melted by the rain and added to the water of the rainfall. The ground was frozen and almost the entire quantity of water found its way quickly into the streams, producing sudden and violent freshets. The ice was broken up and swept down the streams, repeatedly lodging and forming dams which backed up the water until the head was sufficient to sweep them away only to reform further down stream.

In the Grand River, which enters Lake Erie at the harbor of Fairport, the maximum discharge amounted to nearly 16,000 cubic feet per second. Ice dams were repeatedly formed, and when the moving ice reached the lower part of the river it came as a solid wall, rising 10 feet or more above the surface of the water. The vessels and small craft in its way were torn from their moorings and swept out into the lake. When the moving ice met the solid ice at the entrance of the harbor it formed a dam of unusual strength and solidity. It backed up the water to a height of 8 or 9 feet so that it flowed out over the top of the jetties. These structures were not designed to act as dams, and the water under this head found its way beneath them, scouring out the bottom and causing them to settle unequally

and disturbing their alignment. The water finally burrowed under the ice dam scouring out a channel and depositing the eroded material out in the lake beyond the dam, so as to form a bar, upon the crest of which there was but 6 or 8 feet of water. When the ice disappeared the harbor was thus closed to commerce. To restore the channel dredging was resorted to, and it required the removal of 30,000 yards of material to accomplish this result.

A freshet occurred at the same time in the Cuyahoga River which enters Lake Erie at Cleveland, Ohio. The maximum discharge amounted to 28,000 cubic feet per second. The lower part of this river was free from ice because the city had caused tugs to move up and down over it continually to prevent the solid ice from forming. Hence, there were no ice dams, but the discharge was so great that the river had a fall of 14 feet in a distance of 3.5 miles within the city limits. The current developed was very great and vessels were torn from their moorings and three large ships were swept down the river and lodged against the Superior Street Viaduct which is the principal public bridge across the river. The bridge was thereby greatly endangered, the channel was blocked, and the vessels were not extricated from their perilous position for several days. The swift current scoured out the bed of the river in some places and caused extensive deposits in others, and not less than 250,000 cubic yards of sediment and filthy sludge which had been deposited by the city sewers on the bottom of the river was swept out through the jetties in a period of about ten days. The volume of water passing during that period was about 9,000,000,000 cubic feet. A portion of the sediment was deposited in the outer harbor, but the greater part of it was swept into the lake. The deposit in the harbor, however, was sufficient to require extensive dredging to restore navigation.

In the Black River which enters Lake Erie at the harbor of Lorain, a similar freshet occurred causing extensive ice dams which raised the water not less than 12 feet, so that the low land was inundated and the river found temporarily a new outlet to the lake. Bridges were damaged and vessels were swept out and stranded in the meadows.

The Maumee River which enters Lake Erie at Toledo, Ohio, was likewise in a state of flood, and formed an ice dam in the bay about a mile beyond the river mouth. This dam was not less than 600 feet thick and solid to the bottom of the bay and the dredged channel. It backed up the water until it attained a height of 11 feet above the mean stage. Wharves and railway tracks and the lower portions of the city were submerged, bridges were destroyed, and vessels swept from their moorings. The ice dam was not broken for more than two months, but channels were formed under the dam through which the impounded water gradually escaped.

Although the action of floods and ice may at times be very injurious and destructive to artificially deepened channels and

areas, by far the most persistent cause of deterioration is due to the movement of the beach sand under the combined action of waves and currents.

The existence of a sandy beach implies the existence, not far away, of a source of supply of beach-forming material. This is usually a high bluff bank or headland that is being gradually undermined and washed away, the material of which is assorted and transported by the water so as to form the beach in the first place and to maintain it, and perhaps augment it, thereafter. The beach sand is moved in two different ways: First, by the direct action of the waves breaking upon the shore; and secondly by the action of the littoral currents.

When a wave advances into gradually shoaling water so as to feel the retarding effect of the bottom and the diminishing depth, the axis of oscillation of the particles of water ceases to be vertical and becomes inclined toward the shore, the shoreward face of the wave becomes steeper and steeper and finally breaks, and the water flows rapidly up the beach and immediately flows back again. The motion of translation of the water as the depth diminishes becomes sufficiently great to sweep the sand along the bottom, to carry it up the incline, and as the wave returns, to carry it, or the greater part of it, back again. If the crest of the incoming wave is not parallel to the shore line the sand is pushed up the beach obliquely, and as the reflow is nearly normal to the shore the sand is advanced by each successive wave in the direction along the shore in which the waves are running. Another storm in the opposite direction may move it back again, but if, as is usually the case, the prevailing storms are from one direction the resultant movement of the sand will conform.

Upon the Lower Lakes the prevailing storms are from the westward, and as a result there is a constant movement of sand toward the east. If this movement is arrested by a wharf, jetty, or other structure extending outward from the shore, the sand will gather against it, and the shore line will advance accordingly.

The second mode of sand movement results from the action of the shore currents. These currents on the Lakes are not sufficient of themselves to pick up the material from the bottom and move it along; but during storms, when the waves are breaking upon the shore, they stir up the sand at the source of supply as well as upon the beach itself, lift it up and hold it in suspension for a time, the finest and lightest particles being held the longest. If, at this time, there happens to be a current along the shore, or outward toward deeper water in the lake, the material so suspended will move with the current until it gradually sinks and comes to rest upon the bottom. This action may make itself felt in much deeper water than that of the waves alone.

On the Lower Lakes the direct action of the waves produces little or no motion of sand in depths of water greater than 12 or 15 feet, but the currents may carry the suspended material into

any depth, depending upon their velocity and direction and the length of time that the silt can be floated.

At the harbor of Fairport on Lake Erie in the State of Ohio, the sand movement is perhaps as marked and extensive as at any harbor on the Lower Lakes. For this reason it is a particularly favorable place to study the sand movement. The earlier maps are not extensive enough or in sufficient detail to furnish data for a complete and satisfactory comparison, but such a comparison as it is possible to make indicates that not less than 500,000 cubic yards of sand have accumulated in the last 48 years in an area bounded by the original shore line, the west jetty, the 20-foot contour in the lake, and a straight line parallel to the jetty and 1,000 feet west of it. It was possible to extend the comparison only 1,000 feet from the jetty on account of the limited area covered by the old map, but the actual amount of sand arrested by the jetty must be three or four times as great as this. This represents the net result of the sand movement within this area, but it by no means represents the aggregate movement. The conditions are always such as to cause any excavation or artificial deepening to be quickly filled. A single storm, in November, 1901, caused a fill of not less than 20,000 cubic yards to take place in an area 500 by 250 feet in the channel immediately beyond the outer end of the jetties.

A number of observations have been made at Fairport to determine the velocity and direction of the shore currents, and the amount of sediment carried in suspension. The prevailing direction of the currents was found to be from west to east, generally parallel to the shore, but moving outward to pass around the end of the jetties.

In making current observations, weighted rods nearly equal in length to the depth of the water were used. They were submerged for about nineteen-twentieths of their length so that the wind could have very little effect upon them. At the time the current measurements were made, observations were taken to determine the amount of sediment in suspension in the water. Samples of water were taken at a number of different buoys properly located in the direction of the current. These samples were taken about 2 or 3 feet above the bottom, and the amount of sediment in a given volume of water was afterward determined by filtering and weighing. The results showed that the currents might be as great as 1 mile an hour and that the sediment in suspension always diminished as the water moved outward from the shore. The loss of suspended sediment was sufficient to account for a fill across the channel beyond the end of the jetties as great as 0.4 foot in 24 hours during a storm of very moderate violence.

These observations were not taken under conditions to give maximum results. A small boat was used for placing and picking up the floats and for securing samples of water, and it was not possible to send it out at the time of a very severe storm. If it had been possible, no doubt, greater currents would have

been observed, a much larger amount of sediment would have been found in suspension, and its effect would have extended very much farther outward into the lake.

It is evident, therefore, that the forces of Nature are constantly at work to destroy and obliterate the artificially deepened channels and areas which form such an essential part of the harbors of the Lower Lakes, and that no permanent structures can be devised that will adequately protect and maintain them. Periodical dredging will always be necessary to preserve the required depths.

The wisdom and necessity of keeping in a state of preparedness, a dredging plant of sufficient capacity, seaworthy in construction and design, rapid in action, and economical in operation, is therefore too obvious to require demonstration.

The suitability of any harbor for the purpose for which it is designed can best be determined by considering the kind of vessels which make use of it. In the earlier period of the navigation of the Lower Lakes, sailing vessels were exclusively used for the transportation of freight. The fore-and-aft rig was generally adopted and the two or three-masted schooner was the type of the Lake freighter. These sailing craft found difficulty in entering and leaving the jettied harbors and in making their way through the narrow bodies of water which connect the Lakes. Steam tugs were therefore early resorted to to assist them in these places, and the enterprise of the tug owners led them to cause their tugs to cruise far out in the lake to pick up the tows. When the winds were adverse or when there was no wind at all, the tug sometimes proceeded with the vessel to its place of destination. This service proved so expeditious, so convenient, and so advantageous to commerce, that a system of towing was soon developed. The small tug gave place to a steam vessel large enough to carry a cargo itself, and this vessel towed a number of schooners, one behind the other, with long towlines between.

When this system became well established the sail area of the schooners was greatly reduced. Their topmasts and small sails were done away with, leaving them only the lower sails, which were used under favorable conditions to assist the tow-boat, or to give the crew some control over their vessel in case the towline parted. Afterward, a special class of vessels of large size was built to be towed by steamers, and the peculiar shape of hull, both for the steamer and the consort, known as the whaleback, was developed and quite extensively used. The pointed ends and rounded deck which gave this vessel its name were thought to have some special advantages. But this style of construction was soon abandoned, and no more of them are being built. The ordinary form of a ship's hull is now regarded as the best.

Very large cargoes could be carried by the tow-boat and its consorts combined, and great economy of transportation was effected thereby, and for a time it was in high favor. But the

CLEVELAND HARBOR, SHOWING JETTIES AT THE MOUTH OF CUYAHOGA RIVER, AND THE MAIN ENTRANCE IN THE BREAKWATER.

BUFFALO HARBOR, SHOWING TIMBER CRIB WORK, STONY POINT BREAKWATER.

tendency now seems to be to place the same motive power in a larger hull and to dispense with the consorts. Two or three boats combined require more wharf room than a single large vessel. They are difficult to handle in narrow waters and the condition of the consorts is perilous if the tow-line is parted in a storm. The dividing of the crew is disadvantageous, and there is likely to be more delay in loading and discharging several small vessels than one large one. It seems probable now that the future freighter of the Lakes will be a very large propeller of moderate draft and power, that it will carry the cargo in its own hold and will not be embarrassed by other vessels towing behind it.

In the improvement of the harbors on the Lakes the General Government of the United States has constructed jetties and breakwaters, and has secured and maintained a sufficient depth of water in the channels and approaches and in the anchoring grounds. But the General Government has not undertaken the construction of wharves or docks, or the land approaches leading to the same; nor has it provided warehouses or wharf machinery. The construction of these things has been left to those more immediately concerned.

In all the Great Lake harbors these utilities are built, owned, and operated by private individuals or incorporated companies. The level of the Lakes is so nearly constant that inclosed docks are nowhere necessary for the convenience of loading or discharging vessels. The wharves are simple affairs revetted with timber cribs or sheet-piling. The approaches to the wharves are generally controlled by the railway systems of the country, and abundant trackage is furnished so as to place the trains conveniently alongside the ships. Elevators of the best modern construction and design are provided for the handling of grain, and such warehouses, as are necessary, are supplied for the shelter of package freight. Iron ore and coal, the two principal commodities received and shipped at the harbors of the Lower Lakes, need no shelter, but the machinery for handling ore and coal is admirable in its rapidity of action and its economy and labor-saving efficiency.

The Hulett automatic ore unloaders which are in use at the Harbor of Conneaut, Ohio, are considered the best type of unloaders on the Lakes. These machines at times attain a speed of 500 tons per machine per hour. Four of them are installed at Conneaut and can work together on a single vessel, making a total maximum tonnage going out of the boat of 2,000 tons per hour. Some of the largest ships have been completely unloaded by these 4 machines in less than 4 hours.

The McMyler car-dumping machines which are in use at many of the harbors on the Lower Lakes are admirable examples of machinery for handling coal. The earlier machines were of the "end-dumping" type. With these the car is hauled up an inclined girder which is pivoted near the upper end and projects over the vessel to be loaded. The coal car is drawn to the upper end of this girder by means of a haulage engine in the

machine. The car is then clamped and the end gate removed, and the girder with the car upon it is tilted to an angle of about 45° so that the coal is poured into the hatch of the vessel. The objection to this machine is that it requires a particular kind of coal car equipped with an end gate. It has been largely superseded by the side-dumping type. This machine is designed to deliver coal from all sizes and kinds of cars used in the coal trade to all sizes and kinds of vessels. The machinery is designed to handle the coal with a minimum amount of breakage, and to accomplish this the coal slides from the car to the vessel, all vertical drops being avoided. The machine consists of a frame of structural steel about 75 feet high, 52 feet long, and 40 feet wide, and of the necessary machinery for hauling the car into the machine, raising and turning the car over, and for adjusting the different parts to suit the various sizes of cars and vessels.

The operation is as follows: The loaded cars are placed in the yard and are conveyed to a point near the machine one at a time, either by gravity or wire-rope haulage. The car is then pushed up an 8° incline into the machine by a haulage engine operating a small push-car, on a narrow-gauge track, which drops into a pit at the foot of the incline to allow the car to pass over it. After the car is placed in the machine it is clamped automatically and raised to the elevation of a triangular apron when it is turned over and the coal flows down the apron into a telescopic chute which discharges it into the hold of the vessel. The apron may be raised or lowered to allow vessels to pass under it and to accommodate ships of different size. The telescopic chute is designed to swing across the hatch, and a trimmer is provided to deliver the coal under the decks between the hatches. This trimmer consists of a spout attached to the lower end of the chute and arranged to turn horizontally and deliver the coal in any direction desired. The machines are operated either by steam or electricity, and capstans are provided on the docks for moving the vessels promptly. These machines will handle from 20 to 25 cars per hour, delivering 1,000 or 1,200 tons of coal to the vessel in this time.

It must be admitted that the control of these harbor facilities by private companies is not without certain advantages. These companies can always command the best talent to design, erect and operate their machinery, and they have the power to act quickly, and are able to tear out and throw away good and serviceable machinery as soon as something better is discovered. On the other hand, private companies are working for the benefit of their stockholders. They are not interested in reducing the burdens of commerce any further than may be necessary to enable them to secure the business. They are not concerned with the development of any trade but their own, and they are apt to be more anxious to exclude or destroy rivals than to build up the general commerce of the country, or to promote the general welfare. It is certain that the cities and towns at the different ports upon the Great Lakes will sooner or later wake up to their

own interests and will follow the example of the great seaports of the world, and acquire the ownership of their water fronts, build the wharves and land approaches, control the warehouses and wharf machinery, and operate the same for the public good, for the development of the general commerce and with equal justice to all the interests involved.

To sum up in a few words the progress that has been made in the theory and the practice of improving the United States Harbors on the Lower Lakes in the past ten years, it may be stated that when timber cribs are used for the construction of jetties and breakwaters, they are made longer and stronger than formerly, and screw-bolts and steel tie-rods are more extensively used to hold the walls together, and the crib-walls are sheathed with hard-wood plank. Timber superstructures are being generally replaced by concrete moulded in place; and the concrete is often given a profile that offers an inclined surface up which the waves can flow, without shock. Rubble-mound structures are being used instead of timber cribs for breakwaters, and even for jetties where the local conditions are such as to permit it.

Periodical dredging is now known to be necessary to maintain the harbors, and the office of jetties and breakwaters is limited to affording protection and shelter.

Hence, it is recognized that jetties need no longer be parallel, or be built close to the sides of the channel. Adequate dredging plants are being acquired, to be owned and operated by the United States, for the improvement and maintenance of harbors.

Finally, it is admitted that whereas in former times when ships were cheap and small, and harbor building and harbor improvements were comparatively expensive, the ships were made to suit the ports; but now, with the enormous and costly vessels that the requirements of economical transportation demand, the harbors must be made to suit the ships, and the United States is making liberal appropriations and expenditures to widen and deepen the channels and increase the capacity of harbors to keep pace with the growth and development of the Great Lake commerce.

HARBORS ON LAKES ERIE AND ONTARIO

by

MAJOR P. S. REINECKE, Corps of Engineers.*

1923.

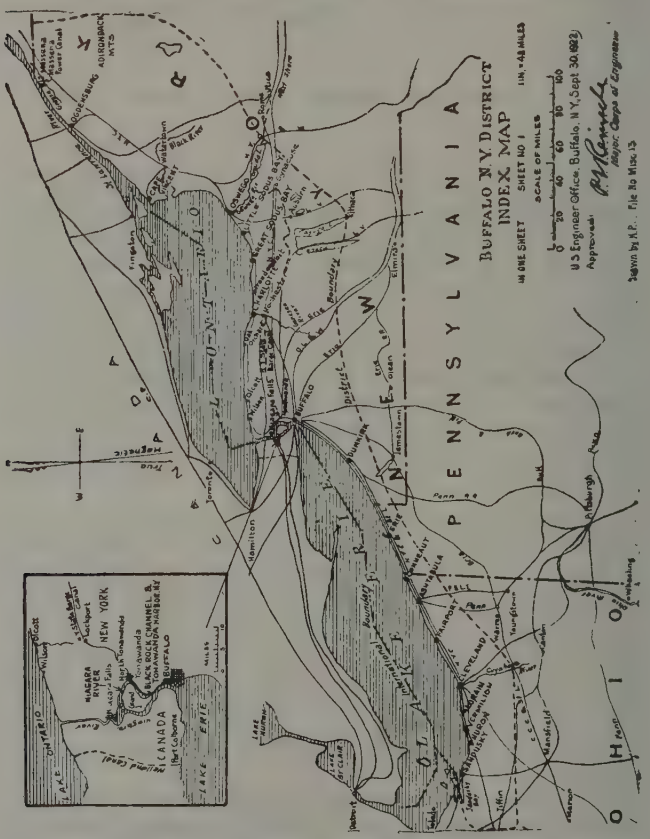
Since the publication of General Kingman's article, there have been very few actually new developments and no great departures from the principles laid down by him, except those required on account of the growth of navigation on the lakes. The population of the eight bordering states has increased, in less than 20 years, from 32 millions to about 43 millions, and the cargo boats have been so developed that now the extreme length is 625 feet instead of the 500 feet extreme length of 1902, while the greatest beam is now 64 feet, with depth of hull of about 34 feet. Whereas, at the time of writing of General Kingman's article, the largest vessels had cargo carrying capacity of 8,000 tons, the cargo record for the year 1920 for one vessel was over 14,000 gross tons of iron ore (on a draft of 21 feet 2 inches), and there are a number of cargoes carried of over 15,000 net tons of iron ore, coal and wheat.

The above will indicate the steps that have been necessary in the development of the lake harbors during the last 20 years. The principles previously evolved in harbor construction have been found, in the main, correct. The development merely had to be carried a few steps further to accommodate the increase in size of cargo carriers and in the amount of commerce handled. The smaller harbors had to be enlarged, the larger harbors had to be deepened, and dredging had to be carried on at a greater rate. Small, tortuous rivers have yet to be widened and deepened, and steps must be taken to cut curves or ease bends to allow the passage of larger vessels; bridges must be removed and replaced.

More efficient and more rapid terminal facilities had to be evolved and installed in order to allow the larger vessels to be "turned around" with the least possible loss of time. This development is yet in process and probably never will be completed, for as fast as additional depth and additional width are provided, or additional means of loading and unloading are evolved, the changes are quickly taken advantage of by still further modification in vessels, and this again calls for even

* Acknowledgment is made to Mr. Emile Low, Assistant Engineer, for his work in gathering voluminous notes from which this paper was prepared.

greater changes in the other matters. In the case of the Cuyahoga River at Cleveland, Ohio, a new system of high level bridges is slowly replacing the original low level swing and bascule bridges, and provision has already been made for the study of the stream with a view to its radical realignment by



cutting out bends. In Buffalo River at Buffalo, N. Y., the bends have been widened and eased by dredging and cutting at every opportunity, and steps are now being taken to utilize more fully the outer harbor at Buffalo because navigation is greatly hampered in the crowded, narrow river which has heretofore carried most of the commerce.

One other feature which will shortly affect general navigation on the lakes, especially Lake Ontario, is the expected completion

in the near future of the new Welland Canal in the Dominion of Canada, connecting Lakes Erie and Ontario. Seven locks on this new canal, capable of passing vesels 800 feet long by 80 feet wide and with low water draft of 25 feet, will replace the present system of 25 locks, which are only 270 feet long by 45 feet wide and 14 feet deep. The completion of this canal will enable ports on Lake Ontario to accommodate a greater share of the lake commerce.

General Kingman mentioned in his article that observation seemed to indicate that the vertical face of several breakwaters might have to be modified by the addition of a riprap apron on the lake side so as to break up the force of storm waves against this face. Further investigation proved the accuracy of this observation, and throughout the harbors in this district this riprapping is now being done as funds and opportunity allow. Considerable progress has been made, especially in front of old timber cribs at Cleveland, Buffalo and Oswego, and this work will be carried to completion as soon as possible. The riprap is now dumped or placed in front of the breakwater and allowed to settle to a state of equilibrium under the action of the waves.

At Cleveland, Ohio, the old timber crib breakwater system has practically all been repaired by removing the decayed wooden superstructure and replacing this with concrete, as indicated by General Kingman. It was necessary to deposit considerable riprap, especially on the lake front of the west breakwater, in order to alleviate, in some degree, the pounding of the waves against the vertical face. The effect of this pounding could be seen in the movement of the various cribs out of the line in which they were originally placed.

There is a curious construction at the main entrance to the Cleveland harbor. The original breakwater had an entrance gap almost directly in front of the entrance to the Cuyahoga River and waves entering this harbor were able to cause such discomfort that it was necessary to devise some protection. Consequently two converging rubble mound spurs 1,250 feet long, with their lakeward ends 700 feet apart, were constructed, each at an angle of about 60 degrees to the breakwater, and attached to the breakwater at their inner ends. This structure effectually cut off all waves from entering the harbor except a small portion of those coming from a northeast direction straight through the two gaps.

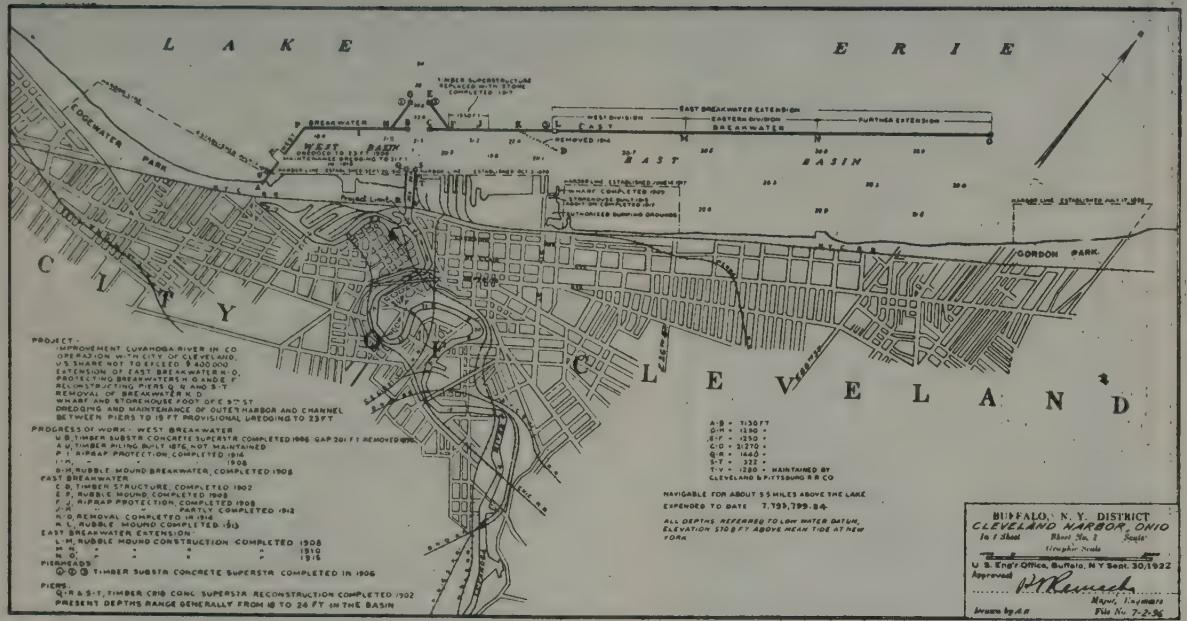
The old east timber crib breakwater of Cleveland harbor has been extended for a distance of almost 18,000 feet. This extension is all rubble mound construction, a portion of it roughly paved, and the balance with very little attempt at the regular placement of stone so as to form a pavement. On the exposed timber crib portion of the east breakwater considerable riprap protection was necessary.

In the construction of the Cleveland rubble mound breakwater a short experimental section was built with a sand core at depth greater than 18 feet below low water datum. It was found, however, that as much as 20 per cent of the sand escaped through the openings of the stone ridges on each side of the core. After the protracted storms of 1903, it was discovered that the upper heavy riprap ridges had settled materially into the sand filling on which they rested, the sand apparently having gone to fill the voids between the stones, and to form a slope on the outside of the ridges.

To prevent further loss the cross section was modified by placing a layer of coarse stone core filling on the inner slope of the rubble stone ridges. Afterwards, the use of sand filling was entirely discontinued and shale was substituted therefor. At the same time the cross section was again modified in that the exterior (or lake) slope of the mound was made somewhat steeper and the inside (or harbor) slope somewhat flatter. Also quarry run stone, weighing from 10 pounds to 5 tons, was used in place of the small riprap, sufficient small stone being required only for proper bedding of the larger stone.

A 2,000 foot section was built in this manner, but in spite of the changes described above a considerable settlement was observed throughout the section, probably due to the working out of some of the shale, and displacement of some of the larger stone. A very considerable settling of the "sand core" section occurred during the storms of 1906. Consequently neither sand nor shale was used for the remaining portion of the breakwater, only quarry run stone being employed, containing not more than 25 per cent of stone weighing less than 1 ton. This was protected by an outside covering at least 5 feet thick, composed of stones not less than 3 tons in weight, set with the greatest dimension perpendicular to the slope. This modified section has now been adopted for all work in the district, and to date appears satisfactory. Sandstone and limestone were both used at Cleveland, the sandstone being apparently the better of the two. Limestone, which had been obtained from one of the quarries for work at various places in the district, showed evidence of disintegration, and its use has since been discontinued. Other grades of limestone have, however, been found suitable.

The present harbor at Buffalo, like that at Cleveland, consists of two parts, an inner and an outer harbor. The inner harbor is formed by the natural stream of Buffalo River, and an artificial channel called the City Ship Canal, and the outer harbor is formed in the open lake by a series of breakwaters. The inner harbor is at present the commercial harbor of the city; but congestion is now so great that steps are being taken looking toward the development and use of the excellent outer harbor, which has heretofore been used mainly as an anchorage ground, and as a protected passageway between the Buffalo River entrance


L A K E
E R I E
EDGEWATER PARK
WEST BASIN
EAST BASIN
EAST BREAKWATER EXTENSION
WEST DIVISION
EASTERN DIVISION
PURTHER EXTENSION
BREAKWATER
REMOVED 1914
GORDON PARK
C L E V E L A N D
PROJECT -
IMPROVEMENT CUYAHOGA RIVER IN CO OPERATION WITH CITY OF CLEVELAND.
U S SHARE NOT TO EXCEED $ 400,000
EXTENSION OF EAST BREAKWATER H-O.
PROTECTING BREAKWATERS N & O AND F
RECONSTRUCTING PIERS Q, Q AND S-T
REMOVAL OF BREAKWATER K, D
WHARF AND STOREHOUSE FOOT OF E 9TH ST
DREDGING AND MAINTENANCE OF OUTER HARBOR AND CHANNEL BETWEEN PIERS TO 18 FT PROVISIONAL DREDGING TO 23 FT
PROGRESS OF WORK - WEST BREAKWATER
U B, TIMBER SUBSTR CONCRETE SUPERSTR COMPLETED 1906 GAP 201 FT REMOVED 1914
A J, TIMBER PILING BUILT 1876, NOT MAINTAINED
P I RIPRAP PROTECTION COMPLETED 1914
L M, " " 1908
B-M, RUBBLE MOUND BREAKWATER, COMPLETED 1908
EAST BREAKWATER
C D, TIMBER STRUCTURE, COMPLETED 1902
E F, RUBBLE MOUND COMPLETED 1908
F J, RIPRAP PROTECTION, COMPLETED 1908
J M, " PARTLY COMPLETED 1912
N O, REMOVAL COMPLETED IN 1914
K L, RUBBLE MOUND COMPLETED 1913
EAST BREAKWATER EXTENSION
L-M, RUBBLE MOUND CONSTRUCTION COMPLETED 1908
M N, " " " " 1910
N O, " " " " 1915
PIERHEADS
Q-Q-Q TIMBER SUBSTR CONCRETE SUPERSTR COMPLETED IN 1906
PIERS
Q-R & S-T, TIMBER CRIB CONC SUPERSTR RECONSTRUCTION COMPLETED 1902
PRESENT DEPTHS RANGE GENERALLY FROM 18 TO 26 FT IN THE BASIN
A-B - 7:30 FT
G-H - 13.90 "
E-F - 12.50 "
Q-R - 16.40 "
S-T - 32.2 "
T-V - 12.80 - MAINTAINED BY CLEVELAND & PITTSBURG R R CO
NAVIGABLE FOR ABOUT 5 5 MILES ABOVE THE LAKE
EXPENDED TO DATE 7,739,799.84
ALL DEPTHS REFERRED TO LOW WATER DATUM, ELEVATION 570 FT ABOVE MEAN TIDE AT NEW YORK
BUFFALO, N. Y. DISTRICT
CLEVELAND HARBOR, OHIO
In 1 Sheet
Sheet No. 1
Scale
Lithophic Scale
U. S. Engr Office, Buffalo, N Y Sept. 30, 1922
Approved
Major, Engineers
Drawn by A.R
File No. 7-2-36

and the canals and channels near the steel and other commercial plants at the southern end of the outer harbor. During the winter months a large number of vessels, usually grain laden, tie up under the protection of the breakwater, waiting to unload their cargoes when conditions permit.

Of the two original jetties at Buffalo only one, the South Pier, now remains in place, and this protects the artificial channel which is an enlarged entrance channel into the Buffalo River. The other jetty has been removed and replaced, at a considerable distance in a direction away from the channel, by a pier constructed by the Delaware, Lackawanna & Western Railroad Company.

As a result of the experience gained in the Oswego breakwater more bolting was provided in the later Buffalo cribs. In some of the timber superstructures at Oswego the cross walls were not built solid, but had a 12 inch space between adjacent timbers. This is the so-called "cob-house' method. This mode of construction is economical of timber but not of sufficient strength to resist wave action in heavy storms. In Buffalo breakwater construction in 1892-93, the cross walls of the superstructure were built solid, and in additon to drift-bolts, screw-bolts were also used. These cross walls after 30 years, are yet intact in many places, athough the decking is gone. In the timber cribs at the Stony Point breakwater (Buffalo), corner posts and side posts were also added, these being screw bolted to the corner ties. These posts, which do not extend up into the superstructure but only to the top of the cribs, are intended principally to strengthen the cribs below water level.

General Kingman stated in his article that, to protect the timber crib breakwaters from excessive pounding due to wave action on the vertical lake face, it was proposed to deposit on the exposed lake side a mound of heavy riprap with general surface slope of 1 on 2, extending upward nearly to the top of the superstructure. This was done, in 1905, on a section of the south harbor timber crib breakwater at Buffalo, having "cob-house" cross walls, with the result that the harbor face was pushed about 8 feet out of plumb at the top. On the other hand, no serious results to the timber crib superstructure resulted from wave action against the vertical lake face of the cribs with solid bulkheads, except where the timber had decayed.

In March, 1905, in a report to the Chief of Engineers on the Buffalo breakwater, it was stated that the north section of the breakwater was not exposed to the severe wave action to which the more southerly sections were exposed, and that the north section had suffered no damage since it was finished. For the remaining sections, it was recommended that where the superstructure was of timber, it should be removed and be replaced with a stone superstructure, and that a *paved* sea slope should be provided, giving practically the same form as the existing rubble

BUFFALO BREAKWATER; TIMBER CRIB CONSTRUCTION.

BUFFALO BREAKWATER; LAUNCHING TIMBER CRIB.

mound or stone section. It was further recommended that where the superstructure was of concrete, the same paved sea slope be provided, so that, when the repairs to the south harbor section then appropriated for should be completed, a continuous paved sea slope with stone and concrete superstructure

N.Y. State Barge Canal Terminal
Approved widening
NORTH BREAKWATER
Concrete Superstructure
Timber Superstructure
HORSESHOE REEF LIGHT
INTERNATIONAL BOUNDARY
NORTH ENTRANCE
Entrance
Proposed Low Water Datum
Completed
Proposed
Removed
ERIE BASIN
U.S. NORTH PIER
HUTSON ELEVATOR SITE
Proj. completed but unreliable
CITY SOUTH LIMITS
CITY OF BUFFALO
BUFFALO RIVER
Buffalo River Dredged 12 ft. 23 acres by City of Buffalo
LAKE ERIE
BUFFALO HARBOR
SOUTH BREAKWATER
Stone 1760 ft
Concrete Superstructure 377
Timber Superstructure 1803
SOUTH ENTRANCE
South Entrance New Breakwater Stone, 1000' Long
Stony Point Breakw'r Timber 1603' long
CITY LINE
Lackawanna Steel Co
1200 FT OF BREAKWATER OWNED BY LACKAWANNA STEEL CO.
PROJECT To form outer harbor protected by a breakwater, system of the timber crib and rubble mound, types: to construct south pier at the entrance to the inner harbor: To dredge entrance channel to the inner harbor and remove the Hutson Elevator site to a depth of 21 ft at low water datum: to deepen areas A, B, D, F, G, and Triangular Area in the outer harbor and north entrance to 21 ft and Area C in north entrance to 23 ft. at low water datum.
Project completed except deepening of area F south of middle gap
Maintenance dredging required periodically
Breakwater completed as follows: Timber crib 2976 lf: timber crib with concrete or stone superstructure 1178 lf: rubble stone 8250 lf: Total 12404 lf. Concrete superstructure on entire length of south pier 1760 lf: North pier removed by Del. Lackawanna & Western R.R. under permit of Secretary of War which makes the entrance channel to inner harbor 200' to 250' wide.
The normal annual variation of water level is 3.0': Low water datum 2 ft. below mean lake level.
Total expenditures to Sept. 30, 1922.
$6,820,137.48
BUFFALO HARBOR, N.Y.
IN ONE SHEET
SHEET NO 1
1 30000
SCALE OF FEET
0 2000 4000 6000
U.S. ENGINEER OFFICE, BUFFALO, N.Y. SEPT 30, 1922
Approved:
Major, Corps of Engineers.
Drawn by M.P.J. File No Misc. 78

would exist from the north or main entrance of Buffalo Harbor to Stony Point.

Repairs of damages due to storms in 1904 were made in the south harbor section of the breakwater in conformity with the above recommendations, as were repairs due to storms in January, 1907. Extensive repairs to be made in 1923 are to be similarly carried out.

In the original plans for constructing new superstructures

of concrete to replace the old timber ones, it was found extremely difficult to preserve the integrity of angles at the bottom of the profiles when building the concrete in place. Consequently a row of large pre-cast concrete blocks partly submerged were placed along the lake and the harbor faces of the breakwater, the blocks resting on the timber cribs. The concrete of the superstructure was then poured over and between the blocks. The lake face blocks at Buffalo were 6 feet long, 4 feet 2 inches wide, and 4 feet high; the harbor face blocks were of the same length and width, but were only 3 feet 6½ inches high. Imported English portland cement was used, and also natural American cement in the construction of these concrete tops. The natural cement did not prove satisfactory.

The 1910 linear feet of monolithic concrete superstructure constructed in 1887-1889, at the north end of the old breakwater, was composed of one part cement to one and one-third parts sand, four parts pebbles or gravel and four parts broken stone. Very little water was used in mixing the concrete. An examination of this superstructure in 1922 shows well defined lines about 1 foot apart, apparently the same lines along which the layers of concrete were deposited and rammed. The excessive ramming, which had to be resorted to, thus apparently did not bring the water to the surface and in places left the concrete in a porous condition. The concrete was also too lean a mixture (less than 1-3-6). This, coupled with the fact that the structure was built of two classes of cement, resulted in crevices and lines of demarcation. As water entered these beds and cracks and froze, many slabs of concrete separated, and the action of storms has broken them up, and, to some extent, has dislodged the various blocks on the lake face side.

The tops of the banquette and parapet were finished with a thin layer of concrete about 6 inches thick. In the course of time, these layers have become loosened and separated, and in many cases washed overboard. Some of the concrete blocks, especially on the harbor side, are partially disintegrated and rounded off.

The superstructure built in 1891, and apparently constructed in a manner similar to that described above, is, however, in a better state of preservation. Modern methods of concrete construction, with good cement, would have obviated the defects noted.

A type of concrete superstructure not mentioned by General Kingman, but tried out at Buffalo, is the so-called "shell construction", consisting of inner and outer longitudinal walls with cross wall connections all of concrete, the interior spaces or cribs being filled with rubble stone, and the whole covered with a heavy deck of concrete. The different walls were formed in place on large pre-cast concrete blocks, such as mentioned above, with their bases laid 2 to 2½ feet below mean lake level

BUFFALO BREAKWATER; CONCRETE BLOCKS ON TIMBER CRIB SUB-STRUCTURE.

BUFFALO BREAKWATER; END VIEW OF THREE PARTS COMPOSING SUPER-STRUCTURE.

or at about low water datum. This construction was developed for use on certain cribs that were sunk in water where the underlying stratum was composed of such a soft clay that much difficulty had been experienced in keeping the cribs upon this yielding foundation in position, some of them sinking as much as 8 feet and also being displaced sideways. It may be said in passing, however, that the integrity of the crib as a whole did not seem to be greatly disturbed. Owing to this instability of foundation cribs, the shell concrete superstructure has also been displaced at various places, causing fractures in the concrete. This construction was of the usual parapet banquette type.

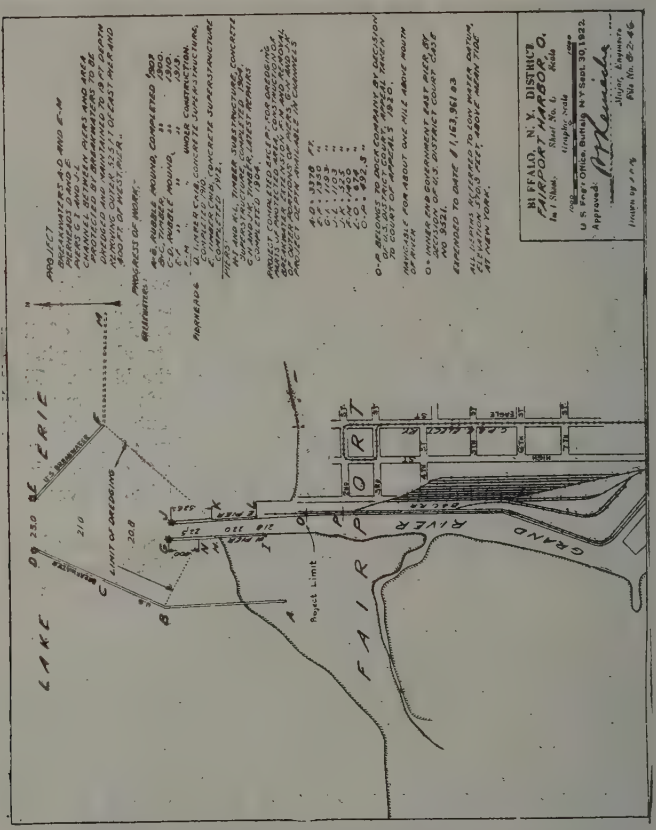
Another section of shell concrete superstructure to replace timber crib superstructure was constructed in 1901-2, with practically the same cross section as the old type but with larger and heavier blocks. This superstructure shows some slight cracking on the harbor side, at the bed joint of the heavy top slab, where it rests upon the top of the wall section. In 1902-3, 3 of the face blocks on the lake side were washed down or drawn out of the structure. The spots were later well covered and protected with riprap, as also was the remainder of this concrete section, the riprap being carried up to about plus 3 feet, or even with the top of the lake face of the blocks. This riprap has now settled down to the water surface along half the structure, and along the other half it extends from 1 to 8 feet above mean lake level. This portion of the breakwater is subject to many heavy seas; it is practically at right angles to the axis of the lake, where the wind has a sweep of the entire length of the lake.

Several lake side concrete blocks have been washed out of the structure since 1902. It is believed that the blocks were cast too short in length. The blocks should have been longer with the inner end bearing on a longitudinal timber.

There now remain in the Buffalo breakwater system only the Stony Point section and a few other isolated sections where the timber crib superstructure has not yet been replaced by stone or concrete. A contract has, however, been let for this work, which will in all probability be completed by the end of the next working season (1923) when all the breakwaters at Buffalo, with the exception of 216 feet at the extreme southern end of the South section, will be of either rubble mound construction or have a stone and concrete superstructure on timber crib substructure, protected by a riprap apron on the lake face.

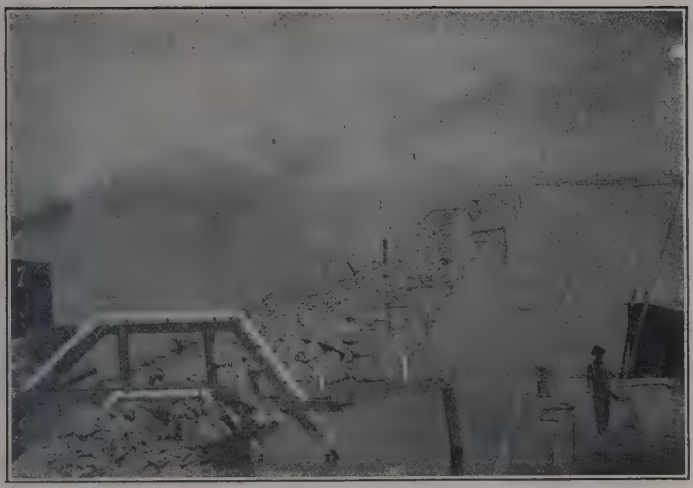
At Fairport, Ohio, it was found necessary to extend the original detached timber crib breakwater on the west. This breakwater was carried to the shore in order to protect the harbor from undue shoaling from the westerly currents, and was extended lakeward for protection of the entrance to the River. The shore connection and the extension are both of

rubble mound construction. The original timber crib breakwater is still in place, but will shortly need replacement of its superstructure. The east breakwater, which is a converging-detached structure, is now being prolonged by means of an arm, parallel to the shore, and as soon as this construction is completed the outer ends of the two parallel river piers are to be



removed for 400 or 500 feet, so as to allow for the better "line-up" of vessels after entering the harbor, preparatory to entrance into the river. The present east breakwater is constructed entirely of rubble mound. It was completed in 1913.

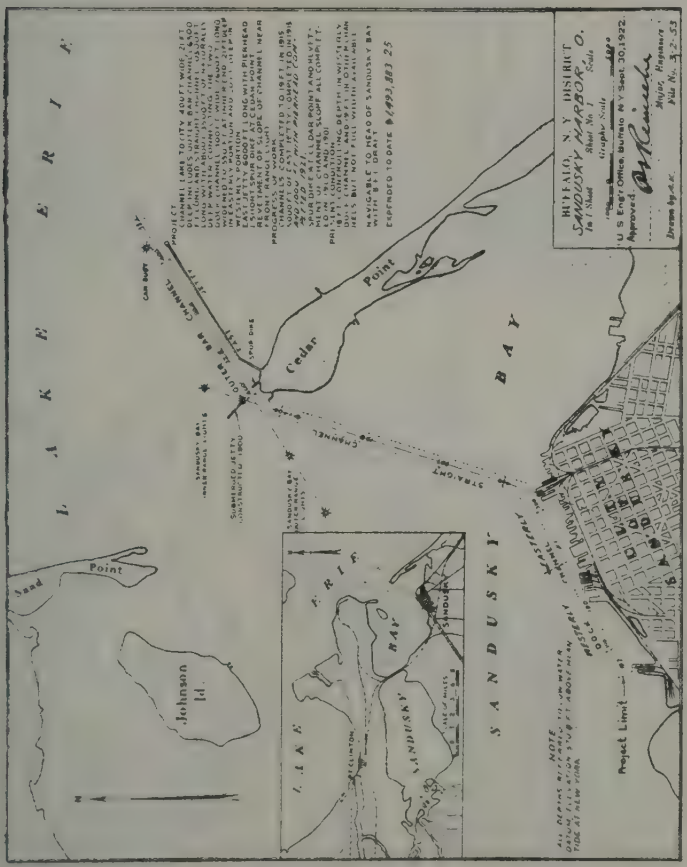
The shore end of the west breakwater is composed of a core of small riprap stone flanked on each side by a ridge of quarry run stone, upon which is placed a covering of large stones



BUFFALO BREAKWATER; RUBBLE MOUND CONSTRUCTION.

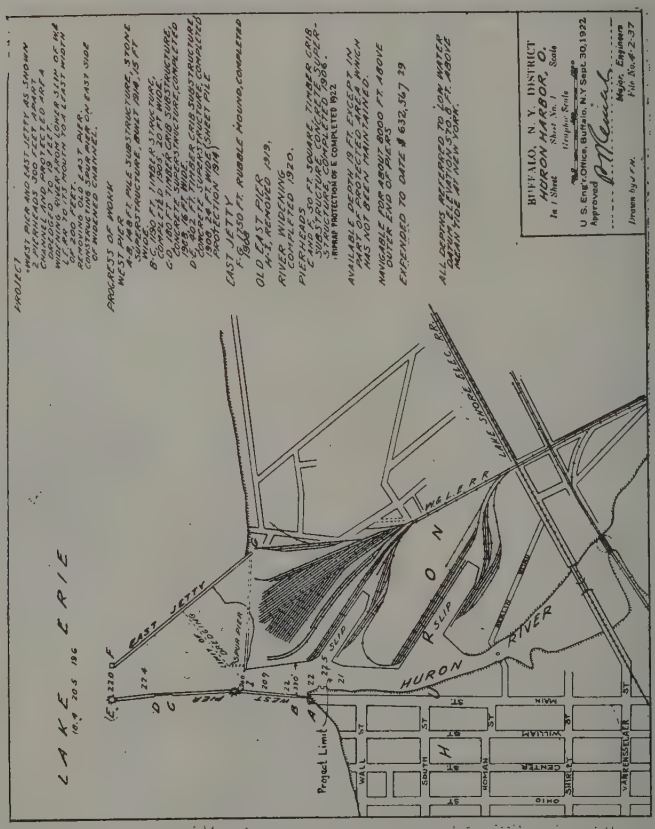
BUFFALO BREAKWATER; RUBBLE MOUND SECTION.

weighing from 4 to 8 tons, laid irregularly to a height of 8 feet above mean level. The harbor slope is 1.3 horizontal on 1 vertical, and the slope on the lake side 2 horizontal on 1 vertical. In building the outer end of the west breakwater the construction was varied somewhat. There is a central core of rubble stone of various sizes covered with large stone, with the



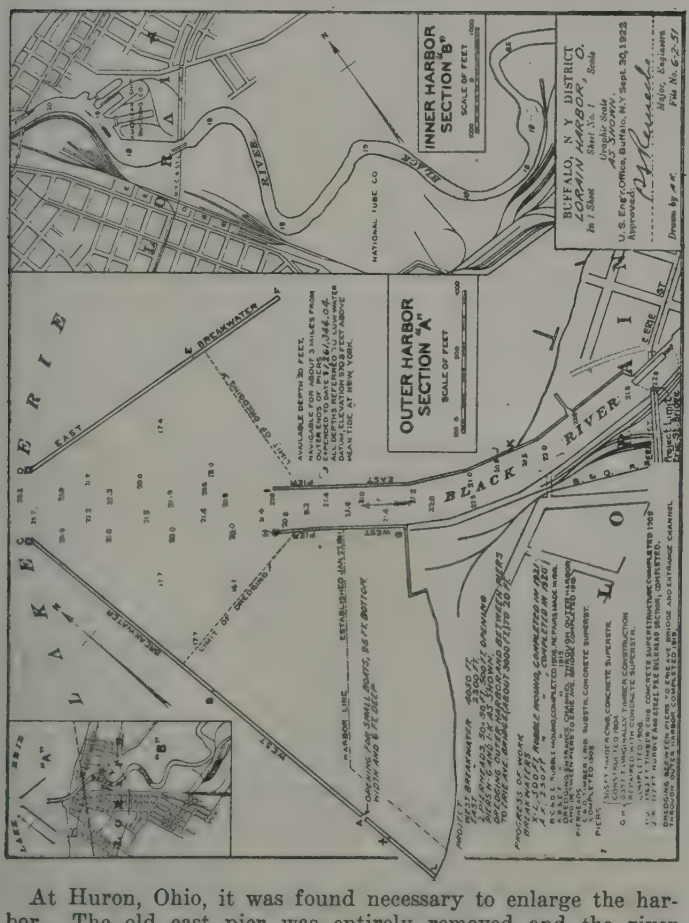
harbor and lake side slope 1 on 1½. At the water line there are berms 5 feet wide, and above these berms the large stones were laid to a height of 8 feet, more regularly and compactly placed than those on the lower slopes. The outer section of the east breakwater (rubble mound) is similar, with but slight modifications, to that of the west breakwater. The east breakwater has smaller sections as it was built in shallower water,

having depth of 14 to 16 feet. The lower core consists of quarry run stone, any size, free from excessive amounts of sand; this core is covered with stone weighing at least 3 tons, the largest being used in the upper portions of the covering on the lake side. The upper core consists of a mixture of quarry run stone such as to insure dense construction, the minimum weight



of individual stones being 500 pounds, and fifty percent being 1 ton and over; the top covering consists of stones weighing not less than 3 tons. The individual stones extend at least 5 feet into the work perpendicular to the outer surface of the breakwater. The top of the rubble mound is 6 feet above mean lake level of Lake Erie.

Since the publication of General Kingman's article, the harbor of Sandusky, Ohio, has been modified mainly by the addition of 6,000 feet of jetty, which has all been constructed along the east side of the outer bar channel beyond Cedar Point; its object is to protect this channel from the wave wash and from filling with sand, which, in this locality apparently has a travel from east to west, due to N. E. storms.

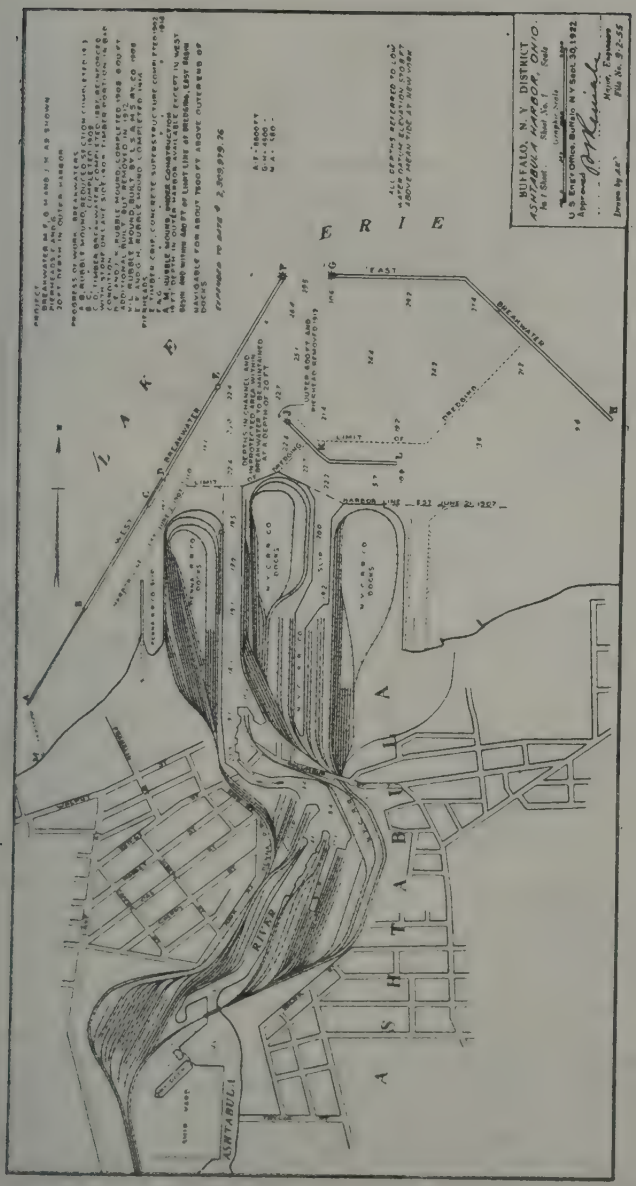


At Huron, Ohio, it was found necessary to enlarge the harbor. The old east pier was entirely removed and the river widened from its mouth to the lower boat slip. The timber crib west pier was prolonged over twice its original length, and a concrete superstructure placed on its outer end. An east jetty was also constructed at an angle of about 30 degrees to the

west pier, the two enclosing a small protected basin outside the entrance to the unloading slips in the Huron River. The east jetty is constructed of rubble mound throughout, built in accordance with the principles enunciated in General Kingman's article. The top blocks of the breakwater weigh from 3 to 8 tons. This rubble mound breakwater is not smoothly paved. It is very effective in breaking the seas and in protecting the harbor.

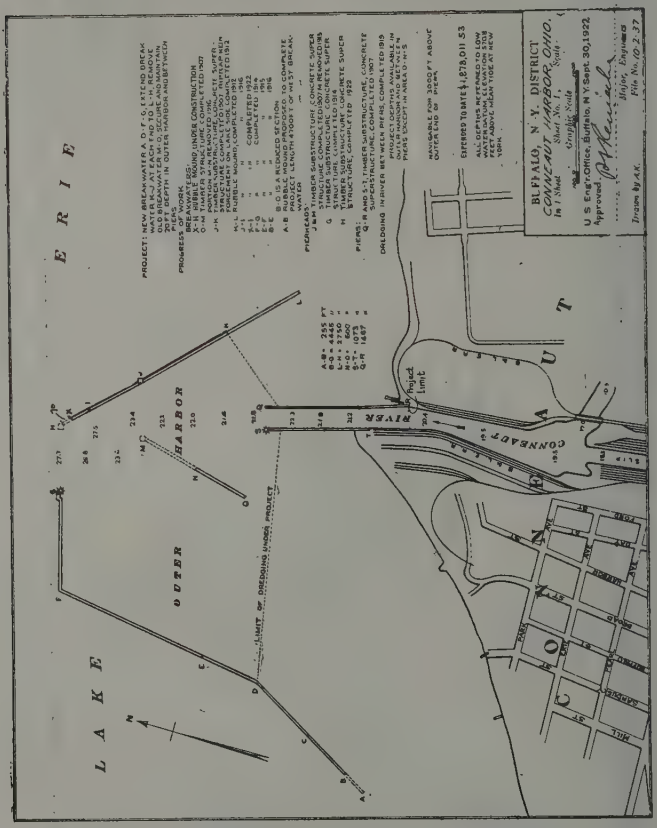
At Lorain, Ohio, the two parallel piers (timber crib with concrete superstructure) at the entrance of Black River had to be protected by a breakwater system, the two arms of which are inclined to the piers at angles of 45 degrees for the west breakwater and 30 degrees for the east breakwater. Here again, a small protected basin has been formed to permit vessels to line up in sheltered water before attempting to make the narrow entrance to the river between the piers. The River was also widened to 250 feet by dredging. Since the time of writing of General Kingman's article, it has been found necessary to extend the west breakwater, which was originally a detached structure, to the shore, in order to prevent the movement of sand along the shore into the harbor. However, a very small gap near the shore end has been left for the passage of small boats; the gap is but 6 feet deep and has a bottom width of 25 feet. The Lorain breakwaters are all rubble mound construction with rough, unpaved finish.

Again, at Ashtabula and Conneaut, the original harbors which were at the mouths of rivers, proved too small for the constantly increasing navigation, connected chiefly with the coal and iron ore trade, so that it was found necessary to enlarge both harbors. The same principle of development was applied to each. The original harbors had each been protected by two converging breakwaters, with the entrance gap (about 500 feet wide) from 1,500 to 2,000 feet lakeward of the River entrance. The outer portion of one of these breakwaters at each harbor was removed, and the outer end of the opposite breakwater was prolonged a considerable distance into the lake. A new breakwater was then constructed 2,000 to 3,000 feet outside the shortened breakwater, converging toward the prolonged breakwater. At each harbor a rubble mound, 2,000 to 3,000 feet long, was built approximately parallel to the shore, before the inclined arm of the new breakwater, which is roughly parallel to the removed portion of the old breakwater, was started. These outer harbors are thus seen to be approximately trapezoidal in shape. In the case of Ashtabula, the original west breakwater was allowed to remain in place. The shore connection is now being completed under contract. In the case of Conneaut, the east breakwater was allowed to remain in place and the west breakwater was rebuilt. Neither of the breakwaters at Conneaut is connected to the shore. At both Conneaut and Ashtabula there is now a large


BUFFALO, N. Y. DISTRICT
ASHTABULA HARBOR, OHIO.
U.S. Engr. Office, Buffalo, N.Y. Sept. 30, 1922
Approved
Major, Engineers
Drawn by
File No. 9-2-55
LAKE ERIE
EAST BREAKWATER
WEST BREAKWATER
ASHTABULA RIVER
ASHTABULA

outer harbor, in which boats may lie, awaiting their turn at the docks.

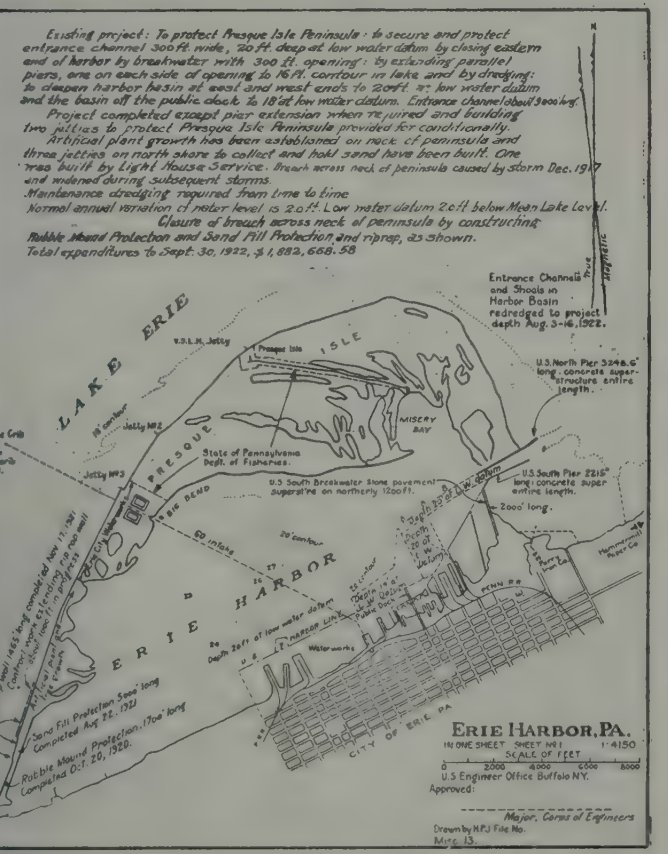
At Conneaut, the direction of the breakwaters with reference to the shoreline and to the winds which prevail during storms on Lake Erie is such that seas having sufficient force to move sand along the bottom tend, in general, to be deflected from


LAKE ERIE
OUTER HARBOR
CONNEAUT RIVER
CONNEAUT CREEK
BUFFALO, N.Y. DISTRICT
CONNEAUT HARBOR, OHIO
Sheet No. 1
Scale
U.S. Engr. Office, Buffalo, N.Y. Sept. 30, 1922
Approved
Drawn By A.K.
Traced By
Checked By
File No. 10.2.37
PROJECT: NEW BREAKWATER A, D, E, & EXTEND BREAKWATER H-K AT EACH END TO L.W. REMOVE OLD BREAKWATER H-K AND REMOVE OLD BREAKWATER H OUTER HARBOR AND BETWEEN PIERS
PROGRESS TO DATE
BREAKWATER E
E-F TIMBER STRUCTURE, COMPLETED 1907
G-H TIMBER STRUCTURE, COMPLETED 1907
J-K TIMBER STRUCTURE, COMPLETED 1907, EXTENSION COMPLETED 1911
K-L RUBBLE MOUND, COMPLETED 1915
BREAKWATER D
D-E COMPLETED 1922
E-F " " 1924
F-G " " 1925
B-C " " 1926
B C IS A REDUCED SECTION
C D IS A CONCRETE CAISSON
A B REDUCED FROM CONCRETE PROJECT LENGTH ABOUT OF NO SY BREAK-WATER
PIERS:
Q AND S-1 TIMBER SUBSTRUCTURE, CONCRETE SUPERSTRUCTURE, COMPLETED 1907
DREDGING IN OUTER HARBOR AND ENTRANCE CHANNEL
DREDGING IN RIVER
ESTIMATED QUANTITIES AVAILABLE IN OUTER HARBOR AND ENTRANCE CHANNEL
ESTIMATED QUANTITIES
ANCHORAGE FOR 3000 FT ABOUT OUTER END OF PIER
DIFFERED TO DATE $1,878,011.53
ALL DEPTHS REFERRED TO LOW WATER DATUM, ELEVATION 573.0 FEET ABOVE MEAN TIDE AT NEW YORK
Project Limit
Limit of Dredging Under Project

the outer ends of the breakwaters and to chase along the faces towards the shore. Such a deflection necessarily results in the movement of sand away from the entrance towards the shore along oblique lines diverging from the channel. The reacting seas and currents are generally away from the harbor entrance. This condition, as soon as the eastern breakwater is entirely completed, is expected to result in maintaining a reliable depth

of water, in reducing to a minimum the difficulty and danger attending the entrance of vessels during stormy weather, and in affording a small, protected area outside of the harbor proper, which will serve many purposes of safety and convenience.

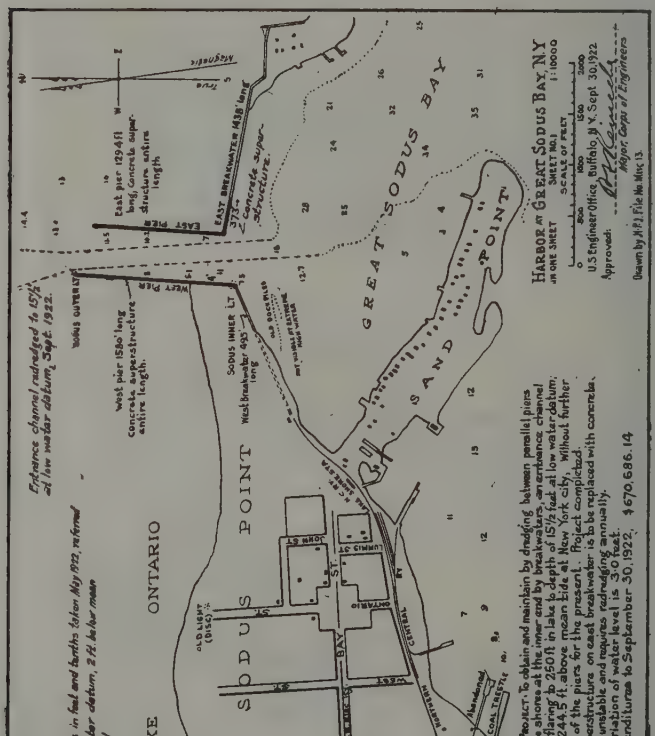
At Erie, Pa. the work done by the Federal Government during recent years has consisted chiefly in maintenance dredging


Existing project: To protect Presque Isle Peninsula: to secure and protect entrance channel 300 ft. wide, 20 ft. deep at low water datum by closing eastern end of harbor by breakwater with 300 ft. opening; by extending parallel piers, one on each side of opening to 16 ft. contour in lake and by dredging: to deepen harbor basin at east and west ends to 20 ft at low water datum and the basin off the public dock to 18 ft at low water datum. Entrance channel about 3000 long.
Project completed except pier extension when required and building two jetties to protect Presque Isle Peninsula provided for conditionally.
Artificial plant growth has been established on neck of peninsula and three jetties on north shore to collect and hold sand have been built. One was built by Light House Service. Breach across neck of peninsula caused by storm Dec. 1917 and widened during subsequent storms.
Maintenance dredging required from time to time
Normal annual variation of water level is 2.0 ft. Low water datum 2.0 ft below Mean Lake Level.
Closure of breach across neck of peninsula by constructing
Rubble Mound Protection and Sand Fill Protection and riprap, as shown.
Total expenditures to Sept. 30, 1922, $1,882,668.58
Entrance Channel and Shoals in Harbor Basin redredged to project depth Aug. 3-16, 1922.
LAKE ERIE
PRESQUE ISLE
MISERY BAY
U.S.L.H. Jetty
Presque Isle
U.S. North Pier 3248.6' long, concrete superstructure entire length.
Intake Crib
Jetty No 2
Jetty No 3
State of Pennsylvania Dept. of Fisheries.
U.S South Breakwater Stone pavement superstone on northerly 1200 ft.
U.S South Pier 2215' long; concrete superstructure entire length.
2000' long.
60' Intake
20' contour
ERIE HARBOR
PENN R.R.
Water works
Sand Fill Protection 5000' long Completed Aug 28, 1921
Rubble Mound Protection 1700' long Completed Oct. 20, 1920.
ERIE HARBOR, PA.
IN ONE SHEET SHEET No 1 1:4150
SCALE OF FEET
0 2000 4000 6000 8000
U.S Engineer Office Buffalo N.Y.
Approved:
Major, Corps of Engineers
Drawn by M.P.J File No.
Misc. 13.

of the harbor entrance between the piers, (which entrance connects a natural deep harbor with the lake), and in the preservation of the neck of Presque Isle Peninsula by means of a riprap dike.

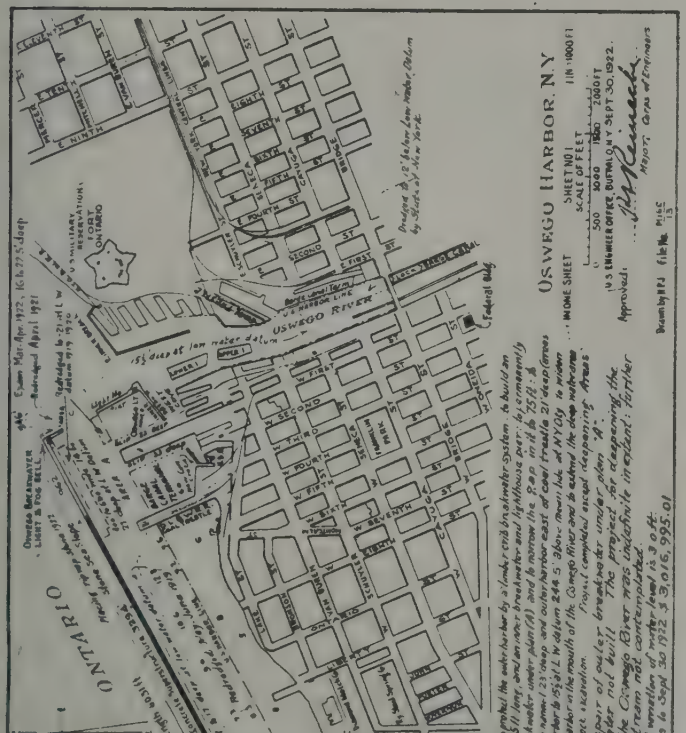
In the harbors on Lake Ontario about the only change of importance that has taken place in the last twenty years, has

been the removal of the timber superstructures at Charlotte, Great Sodus, Little Sodus and in some measure at Oswego, and the replacing of these superstructures with concrete. No breakwater has been built at Charlotte, as smaller vessels have been operating on Lake Ontario than on Lake Erie, and these vessels have in the main, been able to make the entrance between


GREAT SODUS BAY
SODUS POINT
LAKE ONTARIO
SAND POINT
EAST PIER
WEST PIER
Entrance channel redredged to 15½' at low water datum, Sept. 1922.
Soundings in feet and tenths taken May 1922, referred to low water datum, 2 ft. below mean lake level
West pier 1580' long concrete superstructure entire length.
East pier 1294(?)' long concrete superstructure entire length.
EAST BREAKWATER 1438' long
Sodus Inner Lt.
West breakwater 495' long
HARBOR OF GREAT SODUS BAY, N.Y.
SCALE OF FEET
U.S. Engineer Office, Buffalo, N.Y. Sept. 30, 1922
Approved:
Drawn by M.P.J. File No. Misc. 13
EXISTING PROJECT. To obtain and maintain by dredging between parallel piers connected to shore at the inner end by breakwaters, an entrance channel 150 ft. wide having a depth of 15½ feet at low water datum; elevation 244.5 ft. above mean tide at New York city. Without further extension of the piers for the present. Project completed.
Timber superstructure on east breakwater is to be replaced with concrete.
Channel is unstable and requires redredging annually.
Normal variation of water level is 3.0 feet.
Total expenditures to September 30, 1922, $670,686.14

the piers at Charlotte without special difficulty. The same holds true at Great Sodus and Little Sodus, although these two harbors are examples of that class referred to by General Kingman, in which a breakwater was built on the bar in order to fix its position and stabilize it, and piers were extended out into the lake from the breakwater in order to afford a deeper entrance to vessels

over the bar. The east breakwater at Great Sodus still requires about 1,000 feet of timber superstructure to be replaced by concrete. This is being done as funds become available. The piers and breakwaters at the three harbors above mentioned all have an elevation of about 6.6 feet above low water datum. At Great Sodus and Little Sodus exceptionally good natural harbors



exist after the bar has been crossed. It has recently been found necessary at these two localities to riprap the west face of the west piers, in order to protect the piers from breaching during heavy storms, especially in the timber substructure. In fact, several breaches were made that have necessitated repairs. This riprapping will also be continued from time to time as necessity

indicates and funds become available. It may be noted in passing that in much of the concrete work on Lake Ontario, universal (slag) cement was used, which is "peeling" and wearing off at a rapid rate. This cement is not considered satisfactory for use in work exposed to wave and ice conditions.

At Oswego a large outer harbor has been formed by means of a breakwater with the main entrance at the east end, and a smaller entrance near the western end to allow of the passage of small vessels. The outer breakwater at Oswego was originally composed of a series of stone filled timber cribs 35 feet square with the exception of a few, which were built 70 feet long by 35 feet wide. These cribs were all sunk upon the natural sand and clay bottom of Lake Ontario, except those in the easterly 1400 feet which were placed upon a stone foundation in a dredged trench. Many of the former cribs settled out of line. After the cribs were sunk they were surmounted by a continuous crib superstructure, the parapet of which, 12 feet wide, was about 13 feet above low water, excepting in the southerly 850 feet of the western shorearm where the parapet was only 9 feet high. The banquette was generally 23 feet wide and 5 feet high above low water; exclusive of superstructure, the cribs were generally 20 feet in height.

Experience has shown that the breakwater was not of sufficient strength and stability to withstand fully the force of the waves. The deficiency in strength seemed to be due, in a large measure, to the insufficient bolting of the cribs as originally constructed, as well as to wear in the joints about the boltheads, caused by the washing in and out of sand laden water. No bolts were driven through the tie heads nor at the corners, dependence being placed on dovetails to hold the crib walls together. The breakwater has been breached six times, nearly all the breaches originating in the superstructure, and all in recent years have been caused by failure of the lake face of the wall, which shows a constant tendency to pull away from the side walls. Whenever indications were found that a breach was imminent, the stone in the affected cribs was removed to a depth of 16 to 20 feet, and vertical pieces were fastened to the side walls or to the lateral ties, with lag screws; screw bolts were then run through these posts and the outer wall, the latter being drawn back into place.

The Oswego breakwater is exposed to extremely severe wave action during north westerly storms, when the wind has a sweep of the entire length of Lake Ontario, and creates wave forces at Oswego possibly greater than those experienced at any other Lake port. It is apparent, therefore, that conditions demand unusual strength and weight in breakwater construction. In recent years the timber superstructure has been, and is being, replaced by concrete, the substructure being repaired where

necessary and a riprap protection placed in front of the breakwater. The concrete superstructure has not been built the entire length of the breakwater as yet, nor has sufficient riprap been placed to consider the repairs completed.

A peculiar construction near Lake Ontario, but actually in the St. Lawrence River, is the so-called "breakwater" built at Capt Vincent, N. Y. It is in reality a detached pier to which

U.S. BREAKWATER TOTAL LENGTH 1381.3
Built 1900-1915
Concrete Superstructure 1905-1917
Not considered necessary
Not considered necessary
ST LAWRENCE
RIVER
RAILROAD & STEAMBOAT WHARF
U.S. Fish COMMISSION HATCHERY
CAPE VINCENT
MURRAY
BROADWAY
GOUVELLO ST
N.Y.
Existing project. To build a breakwater parallel with and approximately 500 ft from the railroad wharf, the main breakwater to be 1400 feet long with a return at the upper end 150 ft. long, or so much thereof as is required
Project completed except each end of structure as indicated, not considered necessary.
No dredging in project controlling depth at breakwater 19.0 ft.
Low water datum is 2 feet below mean lake level.
The normal annual variation of water level is 3.0 feet
Total expenditures to Sept 30, 1922.
$ 227 368 64
CAPE VINCENT HARBOR, N.Y.
IN ONE SHEET.
SHEET NO. 1
SCALE OF FEET
1 IN = 300 FT
0 100 200 300 400 500 600 700 800 FT
U.S. ENGINEER OFFICE, BUFFALO, N.Y. SEPT 30, 1922
Approved:
Major, Corps of Engineers
Drawn by A.F.J. File No. Misc 13

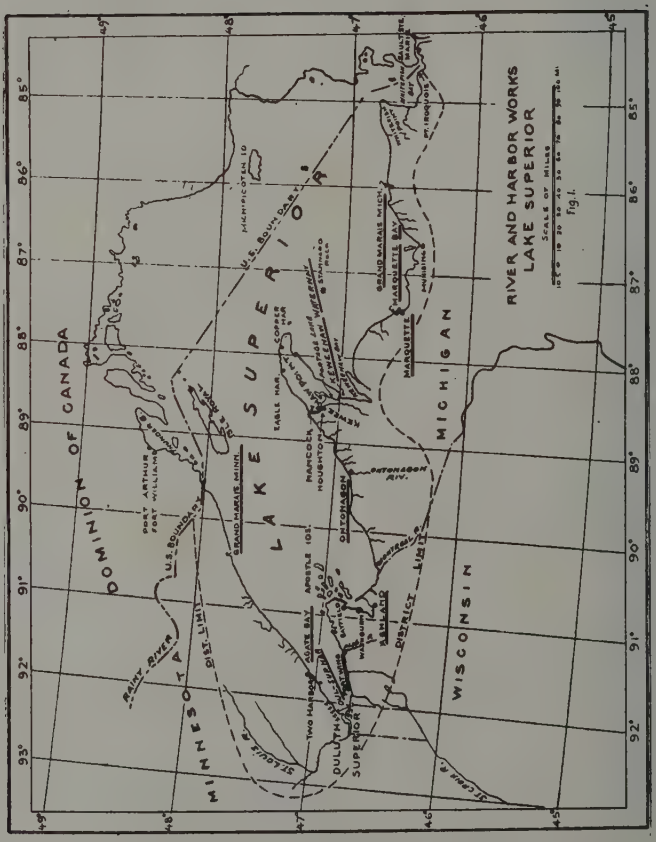
vessels may tie when conditions, caused by storm, fog, etc., are such as to prevent the continuance of their journey through the lake or down the river. In a measure the breakwater protects the wharves at the town of Cape Vincent from wave action, but this is of minor consideration in this case.

General Kingman mentioned, in his article, the possible de-

velopment of dredging upon which great reliance might have to be placed in the future in keeping harbors and especially harbor entrances so deepened as to admit of efficient navigation. His predictions have come to pass. Practically all the harbors on Lakes Erie and Ontario now require a considerable amount of maintenance dredging annually. The present project depths of all the principal Lake Erie harbors are 19, 20 and 21 feet, low water datum, except in a few special cases, where a depth of 23 feet has been authorized; one of these is at the entrance to Buffalo harbor, where this depth is necessary to counteract the extreme fluctuations due to "surges" and wave action on account of storms.

The self-propelled hopper type dredge *Burton,* which was spoken of by General Kingman, has been operating in Lake Erie, with ever increasing demands on it, and with continually increasing efficiency. Some years ago it was able to maintain the harbors working only one shift a day. Last season it was necessary to operate two shifts a day, and the season closed before all the dredging possible, or even desirable under the subprojects in Lake Erie, was completed. This extra work is caused by increased shoaling in the harbors, and in the harbor entrances, as the "jettying" effect of the piers and other breakwaters diminishes. In addition to these demands, the Harbor at Toledo, Ohio, (which is in reality the Maumee River, a stream carrying large quantities of silt) has required whatever time could be spared by the dredge in order to maintain project depth and to widen the long River channel as nearly as possible to project width. It is contemplated next working season to operate the dredge 24 hours per day and it is believed that all necessary work will then be accomplished. Considerable shoaling takes place in many of the harbors during winter storms and spring freshets before the opening of navigation; each port makes urgent demands that the dredge be sent to its particular locality first in order to open a channel through the bar, so that navigation may be carried on efficiently at the project depths. It is the policy of the District to send the dredge to such harbors as are in most urgent need of emergency dredging in order to open a small passage through the bar first, and later on to allow the dredge to return to remove the shoaling from the entire harbor to project depth. On account of the proximity of the large harbors in this district to one another, an excessive amount of time in these transfers is not lost, and such time as is lost, although it reduces the efficiency of dredging operations somewhat, really increases the efficiency of harbors from the viewpoint of shipping, which, in the final analysis, is the reason for operating the dredge. During the past season, the dredge removed over 600,000 cubic yards of material at a field cost under 12½ cents per yard, and at a gross cost under 16 cents per yard.

The harbors on Lake Ontario have been kept open by use of the dipper dredge *Sodus*, which was in operation at the time of the writing of General Kingman's article. There has been no special development in the use or operation of this dredge except that it was necessary to operate here also on a two shift basis during the past season, in order to keep the harbors open. It was also necessary to transfer this dredge to Lake Erie for work at Buffalo and Black Rock Channel.


RIVER AND HARBOR WORKS
LAKE SUPERIOR
SCALE OF MILES
Fig. 1.
LAKE SUPERIOR
DOMINION OF CANADA
MINNESOTA
WISCONSIN
MICHIGAN
DULUTH
SUPERIOR
PORT ARTHUR
FORT WILLIAM
PRINCE ARTHUR'S LANDING
GRAND MARAIS HARBOR
GRAND MARAIS MICH.
MARQUETTE
MARQUETTE BAY
PRESQUE ISLE
ONTONAGON
ONTONAGON RIV.
HOUGHTON
HANCOCK
EAGLE HARBOR
EAGLE RIVER
KEWEENAW POINT
ISLE ROYALE
MICHIPICOTEN ID.
U.S. BOUNDARY
INTERNATIONAL BOUNDARY
ST. LOUIS BAY
ST. LOUIS RIVER
TWO HARBORS
KNIFE RIVER
AGATE BAY
AMYGDALOID ISLAND
MINNESOTA POINT
SAND BAR
BARK BAY
DISTRICT LINE
PIC RIVER
MICHIPICOTEN HARBOR
PAINT RIVER
STATE LINE

UNITED STATES HARBORS ON LAKE SUPERIOR

by

MAJOR EDWIN H. MARKS, Corps of Engineers *

1923.

PHYSICAL CHARACTERISTICS OF LAKE SUPERIOR.

Lake Superior (Fig. 1) is the greatest expanse of fresh water on the globe.

Its length, along the steamer track from Duluth, Minn., to Pt. Iroquois, Michigan, is 383 miles, and its greatest breath is about 160 miles. Other dimensions and characteristics are as follows:

Area of water surface of lake	31,800	sq. miles.
Area (land) drainage	48,600	" "
Total area of basin	80,400	" "
Average rainfall per annum	28	in.
Maximum recorded depth of lake	1,180	ft.
Mean surface above mean sea level	602.29	"
Mean surface above mean surface of Lake Huron	21.16	"
Low-water datum for harbor improvements, above mean sea level	601.6	"

The average or normal elevation of the lake surface varies from year to year. During the course of each year the normal level is subject to a consistent seasonal rise and fall, reaching its lowest stage usually about the close of winter and attaining its high stage during the late summer.

Highest annual stages (Maximum monthly mean height of each year of last five years) ..... 0.92 to 1.27 ft. above low-water datum.

* This paper is based upon an article prepared by the late Colonel David DuB. Gaillard, Corps of Engineers, for the International Engineering Congress of 1904. Statistical data has been revised and brought up to date, and new matter added where necessary. The United States Lake Survey Bulletin has been freely used in the preparation of this paper.

Lowest annual stages
(Minimum monthly mean height of each year of last five years) ..... 0.16 below to 0.54 ft. above low-water datum.

Highest monthly mean
(1860-1921) ..... 2.48 ft. above low-water datum.

Lowest monthly mean
(1860-1921) ..... 1.07 ft. below low-water datum.

Greatest annual fluctuation
(based on monthly means) .. 2.67 ft.

Least annual fluctuation
(based on monthly means) .. 0.53 ft.

Through joint action on the part of the United States and Canada, the fluctuation of Lake Superior is being regulated by compensating works located in the St. Mary's River at the head of St. Mary's Falls, which consist of dikes and sluice gates so operated as to vary the volume of discharge from the lake. The purpose of this regulation is to neutralize the changes in flow consequent upon diversions of water around the rapids for power development, and to limit the fluctuation of the lake surface within an ordinary range of 1.5 feet, between elevations of from 0.5 foot to 2 feet above low-water datum, and within a maximum range of 2.5 feet above low-water datum.

The average date of opening of navigation at St. Mary's Falls Canal, Michigan, is April 25th, and the average date of closing of navigation at the same place is December 7th.

The middle part of the lake is not known to freeze, although at times a temperature as low as 41° fahr., below zero, has been recorded along its shores. One winter of exceptional severity the ice extended out so far that no water could be seen from any land around the lake. It is probable, however, that there was at that time a body of open water in the middle portions, as otherwise a drifting of the fields of ice around Keweenaw Point could not be explained.

The maximum thickness of ice in the harbors in Lake Superior varies from 12 or 15 in, to 3 or 4 ft., depending upon the severity of the winter and upon the particular locality considered.

The average date of closing of the different harbors by ice varies from November 19th to January 11th, and the average date of opening varies from April 20th to May 5th.

In addition to its size, Lake Superior is characterized, when compared with the other Great Lakes, by greater depth; greater elevation of its surface above sea level; its high and rocky shores, especially on the north; its irregularity of outline; the lower temperature of its waters, and greater prevalence of fog and ice. Its season of navigation is shorter, and it has less rain, but has

about the same snowfall and storm-wind velocities as the other Great Lakes. The seas, however, are more violent and the waves longer and higher on Lake Superior than on any body of fresh water in America and probably in the world.

The prevailing storms are from the northeast, north and northwest, and during storms the water rises less on the lee shore and falls less on the weather shore than on the shoaler lakes, as the greater depth facilitates the flow of the lower return currents.

Local magnetic attraction, or disturbance of the compass needle, is more prevalent than on the other lakes, and is strongest at particular localities along the north shore, a change of 19° occurring at one locality in a distance of but 650 ft. Fortunately, however, no disturbances of this magnitude have been encountered at any considerable distance from land.

The difference in level between Lake Superior and Lake Huron is overcome by canals and locks. There are three canals—two on the United States bank of the St. Mary's River, 1.9 miles in length, each provided with two parallel locks of a single lift, and the other on the Canadian bank of the river, 1.1 miles in length, provided with one lock of a single lift.

The smallest and oldest of the United States locks is the Weitzel Lock. It was opened in 1881 and continued in service until 1914 when its use was temporarily discontinued. It is 515 feet long in chamber (usable length 480 feet), and 80 feet wide, narrowing to 60 feet at the gates, with low-water depth of about 13 feet. It is operated by hydraulic power.

The Poe Lock, which for some years had the distinction of being the largest canal lock in the world, was opened in 1896. It is 800 feet long in chamber, 100 feet wide with depth of 18 feet at low water, and is operated by hydraulic power.

The Third and Fourth Locks, opened in 1914 and 1919 respectively, are of similar dimensions. They are 1350 feet long, 80 feet wide, and have least usable depths of 24-½ feet. They are operated by electric power.

The Canadian lock, opened in 1895, is 900 feet long, 60 feet wide, with depth on sills of about 19 feet. It is operated electrically.

Through the United States canal alone passes a marine tonnage much greater than that through any other canal in the world, the freight so carried in 1916, the year of heaviest traffic to date, aggregating over 75 million tons. American and Canadian canals together in that same year passed almost 92 million tons.

FORCES TO WHICH WORKS ON LAKE SUPERIOR ARE EXPOSED.

Wind.—The maximum observed wind velocities on Lake Superior during the navigation season, as reported by the U. S. Weather Bureau, are given in the following table:

MONTHS	Wind Velocity in Miles per hour.		
	Duluth	Marquette	Sault Ste. Marie
April	70	49	60
May	64	52	53
June	63	56	50
July	56	68	48
August	56	48	50
September	78	61	56
October	65	51	50
November	70	48	52
December	65	54	54

Since the anemometer stations are located at points on shore which are more or less protected from the full force of the wind which sweeps unobstructed over the open lake it is probable that the wind velocities given in the above table are in most cases smaller than those experienced on the open lake.

So far as works of harbor improvement alone are concerned, the action of the wind is harmful only in causing waves, currents, ice movement and changes of water level.

Waves.—The most dangerous forces to which marine structures on Lake Superior are subjected are those developed by wave action.

The late Col. David Du B. Gaillard, Corps of Engineers, in the seasons of 1901-03, carried out observations upon shallow-water waves at five different localities on Lake Superior, securing more than 2,000 observations. The discussion of these observations and of the results deduced has been printed as "Professional Papers, No. 31, Corps of Engineers, U. S. A."

The observations were taken with a view of determining wave height, length and velocity; the relation of the wave hollow and crest to the undisturbed water level; the depth in which waves break; the effect of decreasing depth upon wave velocity; the relation between wind velocity and wave velocity; the static pressure due to passing waves; the maximum wave force developed, as measured by spring and by diaphragm dynamometers; the character of wave impact; the height of waves due to "fetch," and the reduction of wave height on entering a closed harbor.

The greatest observed storm waves ranged in height (hollow to crest) from 14 to 23 ft., and in length from 200 to 275 ft., with velocities of propagation of from 25 to 33 ft. per second.

All observations upon storm waves were necessarily made in relatively shallow water, and no accurate measurements were attempted in the deeper waters more remote from shore. From the thorough investigation of the subject, however, it seems probable that during the most severe storms on Lake Superior, which occur only at intervals of several years, deep-water waves may be encountered 20 to 25 ft. in height and from 275 to 325 ft. in length.

The maximum readings obtained by spring dynamometers,

during the seasons of 1901-1902, at Duluth, Marquette, and Upper Entrance, Keweenaw Waterway, correspond to static pressures of 2,370, 2,055 and 2,525 lbs. per sq. ft., respectively. As these readings extended through but two seasons, it is not probable that they indicate the maximum wave effect which may be exerted against works in their vicinity.

Fluctuation of levels; seiches.—Even on a calm day the surface of Lake Superior undergoes continual fluctuation of level. Sometimes these changes are apparently seiches, resulting from variations in barometric pressure, which may produce changes in level ranging from a few inches to several feet and return to the normal within a few hours or even a few minutes. At other times the level is affected by winds of sufficient velocity to drive the surface water forward in greater volume than that carried by the lower return currents, thus raising the elevation on the lee shore and lowering it on the weather shore. These wind-produced changes may range in amount up to about 2 feet, dependent upon the violence of the storm which occasioned them, but seldom exceed 1 foot above or below normal level, and their duration is governed by the sustained force of the winds. As the wind decreases the water tends to regain a condition of stable equilibrium by a series of oscillations, which may continue for several days, about a "nodal line" at right angles to the direction of the wind and about midway between the two shores.

Owing to its greater depth, the changes of level from these causes upon Lake Superior are not so great as upon a shallower lake, like Lake Erie.

Currents.—The sudden fluctuations in lake level are of benefit in preventing or delaying the formation of ice at the entrances of harbors like Duluth-Superior, Grand Marais, Mich., and Upper Entrance, Keweenaw Waterway, which are provided with large interior basins; for as the lake rises or falls, a strong inward or outward current flows through the entrance channel, tending to prevent ice formation and causing a circulation of the water in the interior basin, which would otherwise become more or less stagnant and impure.

Sometimes the currents thus developed, as in the Duluth Canal, are so great as to threaten underscour of works. To prevent or minimize this action, resort is had to revetting by riprap. In the Duluth Canal the scour of canal bottom has been so great as to cause undue depths, thus tending to endanger the pile foundations of the piers unless the scour is stopped. Steps to this end have been initiated by the placing of an experimental submerged dam perpendicular to the axis of the canal.

Lake Superior is so deep that littoral currents due to winds and waves are seldom strong enough to affect works constructed for harbor improvement. An exception to this rule is at Grand Marais, Mich., where of late years annual shoaling from this cause requiring dredging has occurred.

Only two of the harbors on the lake, Duluth-Superior and Ontonagon, have rivers of any size emptying into them. At the latter place, owing to the small interior basin, the currents due to the river predominate over those due to fluctuations of lake level, while at the former place the reverse is the case.

Ice.—On the harbors of Lake Superior, ice forms earlier, attains greater thickness, and melts later than on any other of the Great Lakes.

Dredging operations and navigation by small vessels are usually suspended on account of ice about the middle or latter part of November, but navigation by large vessels, assisted by ice-breaking tugs, is often maintained until about the 15th of December or later. Ordinarily, the lake proper does not freeze until early in February, although temperatures as low as 25° to 30° fahr., below zero, may have been experienced as early as the previous December.

At most of the harbors on Lake Superior, navigation is opened during the latter part of April.

Although the ice within the harbors varies in thickness from about 1 ft. to 3 or 4 ft., and on the lake from 1 ft. to about 2.5 ft., and, although ice-fields, miles in area, are moved by winds and currents against them, yet in no case has serious damage been inflicted by moving ice upon harbor works on Lake Superior.

These works are often severely tried by another phase of ice action caused as follows: Before the lake freezes over solidly, the water is often filled with floating pieces of ice. Should a storm then arise and the temperature be low, the water, spray and pieces of ice thrown by waves upon the breakwaters or piers are frozen together forming huge masses of solid ice upon the structures, and imposing heavy additional eccentric loads. For example, in the month of March, 1902, the west breakwater at the Upper Entrance, Keweenaw Waterway, was covered by a solid mass of ice 2,000 ft long, 30 to 40 ft. wide, and 20 to 25 ft. high, which imposed an extra load of about 20 tons per lin. ft. upon the pile foundation. By April 19th, 1902, as the result of an unusually mild spring and of the wash of waves against the side next the lake, this mass of ice had been so melted away along that side, that the outer half of the deck of the breakwater was entirely free from ice, while the inner half still carried a heavy load, a large part of which actually hung over the interior face of the breakwater, and imposed a highly eccentric additional load upon the structure. No injury of consequence has as yet resulted to harbor works on Lake Superior from the ice formation just described.

When the ice begins to move in the spring, "ice jams" in the entrance channels often occur. Due to this cause and to the action of masses of ice moved backward and forward by the currents, piers and breakwaters of timber, when not protected by steel or iron plates, are frequently chafed and worn near

the level of the water surface, and especially is this the case at the outer ends of these structures.

The ice jams caused by the floating ice fields frequently form an obstruction to the passage of even the largest of vessels. An extreme case of this occurred in the latter part of May, 1917, when thirty-eight vessels were "ice-bound" within a few miles of the Duluth Canal for two days, while other boats experienced similar trouble at various times and periods up until June 7th. It is a very common occurrence for boats to be thus held up by the ice in the months of April, May and June, although not usually in such large numbers.

Ice action on Lake Superior at times serves to protect works designed for harbor improvement, for example, when the lake freezes over solidly in the vicinity of the works, wave action is entirely prevented for an average period of more than two months.

For some time before the lake freezes, and for a considerable time after the ice disappears from the lake, some protection is afforded to the wooden decks of stone-filled timber breakwaters, and the separate cribs themselves are strongly united by a thick covering of solid ice formed by the freezing of water and spray thrown upon them by waves.

Observations made from time to time show that within a period of 24 hours ice of a greater thickness than 6 in. was never formed on water at any of the United States harbors on Lake Superior, even with a temperature as low as 30° fahr., below zero.

HARBORS ON LAKE SUPERIOR

Compared with the other Great Lakes, Lake Superior is fairly well provided with natural harbors, but these are so situated that at the present time not one of them supports a marine commerce comparable with that of five or six of the more important artificial or semi-artificial harbors on the lake. In other words, the location of natural harbors did not serve to fix the lines of commerce, but, on the contrary, the requirements of commerce demanded the construction of harbors at other points on the lake.

Classification.—The harbors on Lake Superior may be divided into four general classes:

I. Natural harbors requiring little or no improvement, such as Washington and Rock Harbors, Isle Royale, and the harbors at Munising and Pequaming, Mich.

II. Harbors formed by connecting an interior basin or waterway with deep water in the lake by a channel dredged across a bar or spit and protected by parallel piers. Duluth-Superior Harbor and the harbors at Ontonagon and Grand Marais, Mich., and Port Wing, Wis., are examples of this type.

III. Indentations or bays of considerable depth, with wide

mouths opening lakeward, which natural openings have been partially closed by one or more breakwaters. Examples of this class are the harbors at Marquette and Marquette Bay, Mich., Ashland, Wis., and Agate Bay and Grand Marais, Minn.

IV. Protected basins entirely artificial. The Upper Entrance of the Keweenaw Waterway and Superior Entry, Duluth-Superior Harbor are of this class.

Lower Entry, Keweenaw Waterway, is an example of a dredged channel maintained by a single structure fulfilling the double functions of a breakwater and of a pier.

The words "pier" and "breakwater", although in some places used interchangeably, are not so used on Lake Superior, where "pier" is applied to a structure, which helps to confine the currents in an entrance channel, and which is usually normal to the direction of the wave crests, whereas, a "breakwater" is generally parallel to the crests of storm waves, and is constructed to resist their impact.

Class I.

Harbors of this class do not require improvement and will not be discussed here.

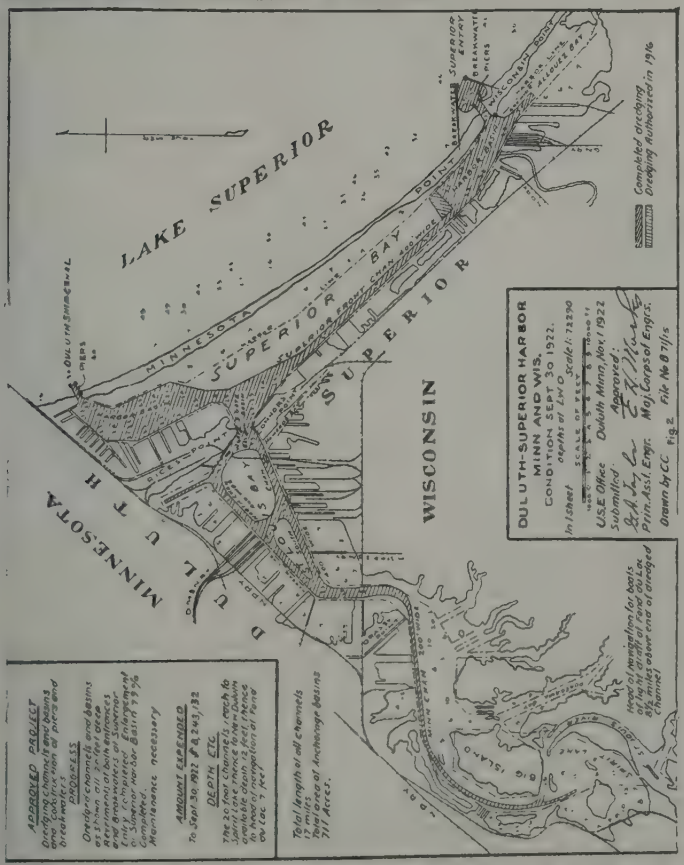
Class II.

Duluth-Superior Harbor.

Located at the head of Lake Superior, this harbor is the most important on the Great Lakes, both on account of its facilities, natural and artificial, and the magnitude of its commerce. For many years but one harbor of the United States (New York) has surpassed Duluth-Superior Harbor in tonnage handled annually, and when it is realized that the harbor is closed to navigation by ice for several months each year this record is all the more remarkable. The harbor is primarily the shipping point for iron ore from the Mesaba, Vermillion and Cuyuna ranges of Minnesota, the shipping point for grain from the Northwest and distributing point to the Northwest for coal arriving from lower lake ports.

The facilities for handling bulk freight are excelled no place in the world. The ore docks, 9 in number, have a combined storage capacity of 942,500 tons. The coal docks, 24 in number, have an aggregate storage capacity of 11,305,000 tons. The 26 grain elevators in the harbor have a total storage capacity of 36,325,000 bushels. A modern cement elevator completes the list of the bulk freight handling facilities, the greater number of which are equipped with the most modern machinery. The facilities for handling package freight, lumber and general merchandise are, however, very primitive and susceptible of

vast improvement. This condition will be somewhat remedied upon the completion of a terminal now under construction which will be operated in connection with a new line of package freight carriers and will be adapted to handling all types of package freight but more particularly dairy products, of which a considerable quantity is shipped to the East.



The harbor (Fig. 2) embraces Superior Bay, Allouez Bay, St. Louis Bay and St. Louis River, and is separated from the lake by Minnesota Point, a remarkable "sand spit" of wave formation, nine miles long and of an average width of about 200 yards, which forms a perfect natural breakwater. Access to the interior basin is had through the Duluth Canal, near the north end of Minnesota Point, and through the Superior Entry, about six miles further south. The entire harbor area is 19 square

miles, with about 49 linear miles of harbor frontage and 17 miles of dredged channels.

The only natural entrance to the interior bays was a winding channel, near the present Superior Entrance, over a shifting sand bar, which had an available depth varying from 9 to 11 feet. The bays, before improvement, were broad expanses of shallow water, 8 or 9 feet in depth, except along a channel through them where the depth was greater but variable.

The United States commenced the improvement of the harbor at Superior Entry in 1867, under a project providing for building two parallel stone-filled timber-crib piers across the bar, and dredging a 12-foot channel between them. These crib piers were subsequently replaced by piers built entirely of concrete.

Operations were begun at Duluth in 1871 under a project providing for the extension of a stone-filled timber breakwater, commenced by the Northern Pacific Railroad. This breakwater was parallel to and about 2,000 feet east of the northern end of Minnesota Point. The extension was completed for a distance of about 1200 feet from shore, but the superstructure and the upper part of the cribs were swept off by storms, leaving the remaining part of the breakwater submerged to a depth of from 1 to 8 feet. This breakwater was never renewed.

The Duluth Canal is an artificial channel cut through Minnesota Point by the City of Duluth in 1870-71, through the enterprize of the Duluth citizens who desired to provide their newly started city with a convenient harbor of its own. In 1873, its maintenance and improvement were undertaken by the United States, in order to secure easy access to an inner harbor, which would take the place of the exterior harbor formed by the breakwater mentioned above.

The improvements undertaken by the United States at this period afforded a navigable depth of about 12 feet, which was deemed sufficient for the needs of commerce at the time. The increase of commerce, however, soon necessitated further improvement. This was authorized by an Act of Congress of 1881 and a new project was prepared which provided for securing 16-foot navigation throughout the harbor and its entrances. This work was completed in 1897 by which time the need for still further improvements had been felt, leading to various Acts of Congress which provided for 20-foot navigation and reconstruction of the two entrances.

Dredged Channels.—The following channels and basins have been prepared for 20-foot navigation by dredging. (Fig. 2).

Lake Entrance to Duluth Canal—30 feet.

Channel through Superior Entry stilling basin—30 feet.

Duluth Canal; between piers, and stilling basin of about 35 acres at Superior Entry—24 feet.

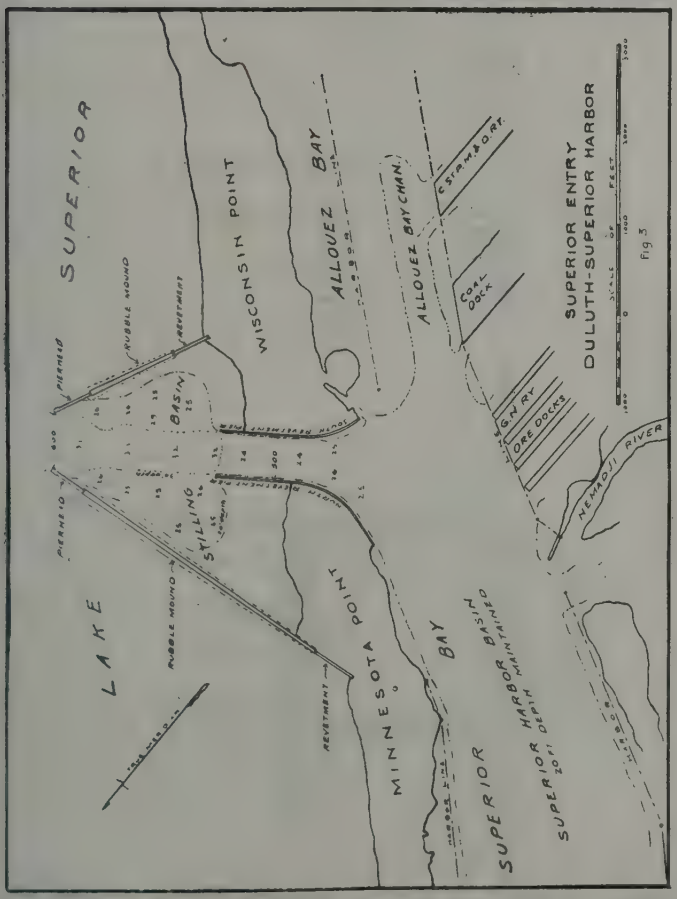
Anchorage basin of 446 acres near Duluth Canal—22 feet.

Anchorage basin of 258 acres near Superior Entry—20 feet.

Channels connecting the two anchorage basins, into and on each shore of St. Louis Bay, into Allouez Bay, up the St. Louis River—aggregating 17 miles in length and of widths varying from 100 to 600 feet—20 feet.

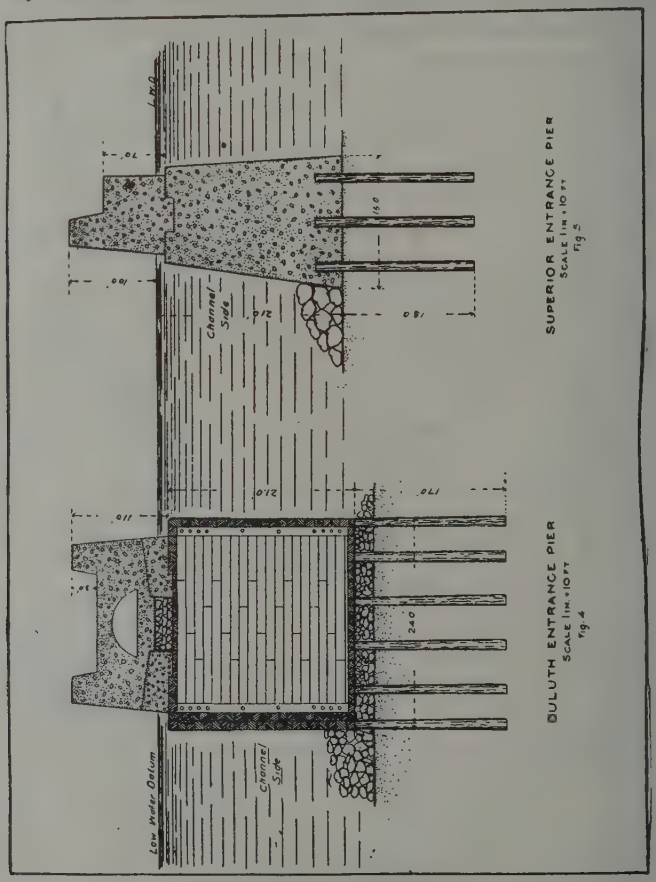
The greater depths are in locations where wave action necessitates the additional depth to provide for 20-foot navigation.

In addition to the Federal project considerable private dredg-



ing has been done to facilitate access to docks and to provide additional channels. An area of about 120 acres in what is known as East Gate Basin, which is opposite the channel connecting Superior and St. Louis Bays, was made available for 20-foot navigation by the regulation of permittees borrowing material.

Practically all of the dredging required in the project was done under contract. Dipper dredges were principally used, although in certain locations where the material was suitable and conditions were favorable to its disposal, hydraulic pipe-line dredges were made use of. The largest plant employed at any one time consisted of nine dipper dredges, one hydraulic



dredge, thirteen tugs and twenty-two dump scows. Costs of the work in later years have varied from 7.5 to 10 cents per cu. yd., depending upon locality, in 1897, to 14.4 cents per cu. yd. in 1919.

Comparatively little maintenance dredging is required.

Duluth Canal.—The original canal, as built by the city, had a width of 250 feet and was formed by timber-crib stone-filled piers. The work of widening the canal from 250 to 300 feet and building new piers was commenced in 1898 and completed in 1901.

The two piers, which are similar in dimensions, extend from deep water of the inner harbor to the original 23-foot depth in the lake, each being about 1700 feet long and projecting about 1150 feet beyond the shore line. The clear width between them for a distance of 1250 feet from the outer end is 300 feet, they then flare out to a width of 540 feet at the inner end.

The stone-filled timber cribs (Fig. 4) forming the substructures are each 100 feet long, 24 feet wide and 21 feet deep. Each crib rests upon 150 piles sawed off near the level of the original bottom. The cribs are armored for a width of 1 foot on top of the berm and for the upper seven feet of the channel face with steel plates one inch thick as a protection against ice and the impact of vessels.

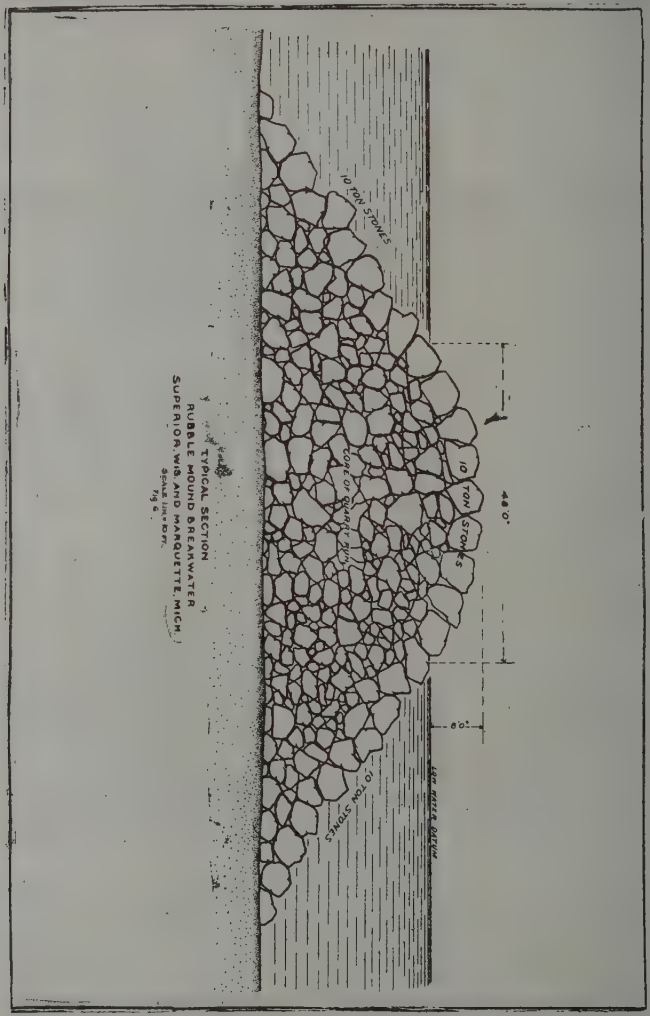
The concrete superstructure is built in monolithic sections 10 feet long, resting on footing blocks cast ashore, and extends from 1 foot below low-water datum to a height of 10 feet above this plane, except near the outer end, where it reaches a height of 18 feet above low-water datum. Each monolith of the typical section contains 42.3 cu. yds. and weighs 85.6 tons. The largest monoliths at the pierheads, which are much wider and higher, contain 209 cu. yds. each and weigh 423 tons.

Owing to the compressibility and elasticity of the deep timber cribs upon which they rest, even the heaviest monoliths during severe storms have been observed to have, at frequent intervals, a total lateral movement of from 0.1 to 0.2 inches, due to the action of high waves traveling parallel to the piers. During these severe storms the wave crests may reach a height several feet above that of the parapet. Iron lamp posts have been broken off 20 feet above low-water datum, both by waves and by blocks of ice hurled by the waves, but the piers themselves have not suffered any injury, other than a slight spawling at the joints caused by the lateral movement mentioned above.

The low gallery in the piers was provided partly to afford access to the lighthouse on the outer ends of the piers in severe storms, a small car to support a person in a reclining position being provided to make the journey.

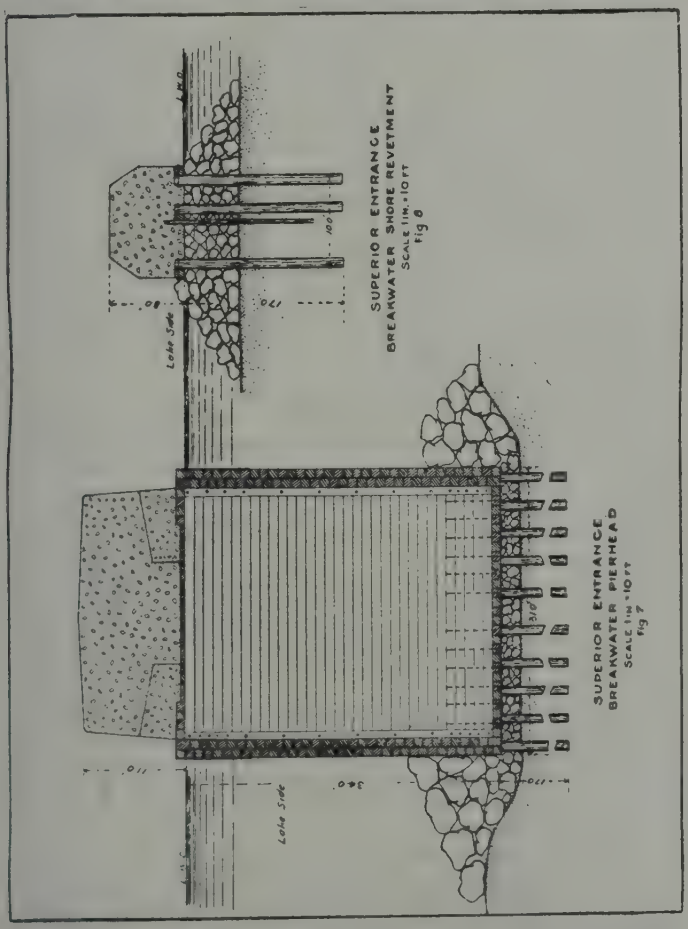
Currents of various degrees of strength are prevalent at the canal, due principally to oscillations of the lake surface. These flow in or out as the lake temporarily rises or falls, and are usually of moderate velocity and short duration. On rare occasions something like a tidal wave occurs, when the current reaches for a few minutes a velocity in the neighborhood of 6 miles per hour, followed quickly by a reverse current perhaps equally strong. These currents cause considerable scour in the canal. The project depth is 24 ft., to which depth the canal was dredged

in 1901, but during the fall of 1922, it showed an average depth of 32.9 feet. A conical shaped hole with maximum depth of 50 feet, occurring very near the intersection of the axis of the canal



with a line joining the pierheads, has been developed by scour. Of late years some riprap has been placed along the base of each pier to prevent undermining, and in the deep hole

was placed in 1921 an experimental submerged dam perpendicular to the axis of the current, with crest about 38 feet below low water. This dam has prevented further scouring at the hole but has induced but little deposit as its crest is probably too low to have that effect. It is expected to place more dams



or weirs in the canal, with their crests at a somewhat higher elevation.

The Superior Entry. (Fig. 3).—The earlier improvement by the Government consisted of two rock-filled timber-crib piers about 350 feet apart, with channel of 12-foot depth. With the growth of marine commerce the channel depth was successively

increased until it was 24 feet and the crib bottom was left from 14 to 16 feet above the bottom of the channel. Owing to this, and other causes, considerable lateral displacement of the cribs resulted and it became necessary to build new piers. The work was carried out between 1903 and 1914 and comprised, besides the two piers, the creation of a wave stilling basin outside of them, formed by two converging breakwaters.

The piers or revetments are parallel and 500 feet apart for about 800 feet from the outer ends, where they begin to flare out, so as to give a trumpet-shaped opening at the inner end. The substructure of the piers is of concrete (Fig. 5) in monolithic sections, 16 feet long, moulded in place around and upon foundation piles, sawed off a short distance above the bottom. The superstructure, extending from about 1 foot below low-water datum, is also of monolithic sections of 12′ 10″ lengths, so arranged as to break joints with the substructure. It was cast in place without the use of footing blocks. The depth between the piers is 24 feet. A description of the plant and construction methods used in the construction of these piers is contained in an article by Mr. Clarence Coleman, Assistant Engineer, appearing in Trans. A. S. C. E., 1904.

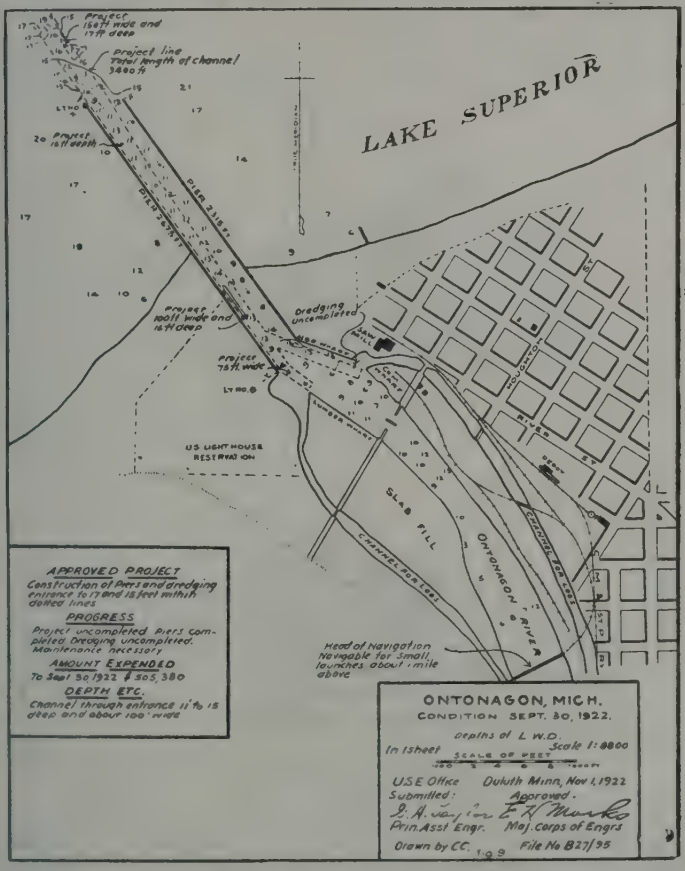
The converging breakwaters, which protect the entrance, are of rubble mound construction (Fig. 6), with concrete pierheads (Fig. 7) on stone-filled cribs resting on piles, and concrete shore revetments (Fig. 8)—the concrete structures being heavily riprapped. The lake ends of the breakwaters are located at the 30-foot contour in prolongation of the entrance channel with an opening of 600 feet between them. The breakwaters, which diverge until they are 2,100 feet apart at the shore line, have aggregate lengths of 4,205 feet of rubble mound, 900 feet of pierheads, and 896 feet of concrete shore revetments. The stilling basin is dredged to a depth of 24 feet over an area of 35 acres and there is a 30-foot channel, 600 feet wide, between the pierheads and the entrance piers.

There are frequent currents setting through Superior Entry, usually simultaneous with and of the same direction as those at Duluth Canal, described above. They are, however, of less velocity than the latter, owing to the greater length of channel and the consequent smaller degree of slope for any difference of level between lake and harbor.

The stilling basin at Superior Entry was provided to afford a safe entry into the harbor in severe northeast storms which upon rare occasions make entry through the Duluth Canal a hazardous undertaking. It has been estimated that waves entering between the breakwaters will be reduced to 0.29 of their original height by the time they reach the revetment piers. To have built such a stilling basin at the Duluth Canal would have cost considerably more in view of the greater depths of water in which it would have been necessary to place the breakwaters.

Ontonagon Harbor, Mich.

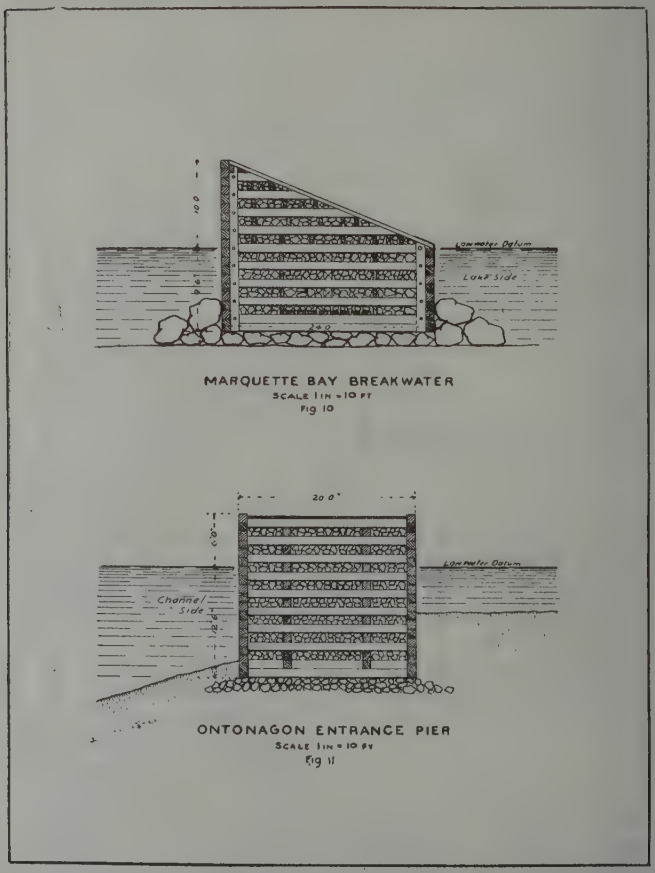
This harbor (Fig. 9) is formed by the mouth of the Ontonagon River, one of the largest streams emptying into Lake Superior. In its original condition the mouth of the river was about 400 feet wide and for a distance of about one-half mile


LAKE SUPERIOR
Project 150ft wide and 17ft deep
Project line Total length of channel 3400 ft
Project 18ft depth
Project 100ft wide and 18ft deep
Project 75ft wide
Dredging uncompleted
US LIGHT HOUSE RESTRICTION
SLAG FILL
CHANNEL PIER LIGHT
ONTONAGON RIVER
Head of navigation Navigable for small launches about ½ mile above
APPROVED PROJECT
Construction of Piers and dredging entrance to 17 and 18 feet within dotted lines
PROGRESS
Project uncompleted Piers completed Dredging uncompleted. Maintenance necessary
AMOUNT EXPENDED
To Sept 30, 1922 $ 505,380
DEPTH ETC.
Channel through entrance 11 ft to 15 deep and about 100 ft wide
ONTONAGON, MICH.
CONDITION SEPT. 30, 1922.
Depths at L W.D.
In 1 sheet
Scale 1:9800
U.S.E. Office Duluth Minn, Nov 1, 1922
Submitted: Approved:
Prin. Asst Engr. Maj. Corps of Engrs
Drawn by CC. File No B27/95

upstream had a depth of 8 to 12 feet. River deposits extended nearly half a mile into the lake with a minimum depth of 6 feet on the bar thus formed. The available depth over the bar changed and the channel shifted from time to time, due to the action of current and sea, making navigation of the harbor uncertain.

The improvement of the harbor was commenced in 1867, the first year that harbor improvement was undertaken by the

United States on Lake Superior. The original project provided for maintaining a depth of not less than 12 feet by the construction of two stone-filled timber-crib piers (Fig. 11), one on each side of the mouth of the river, and by dredging the channel between the piers. This project was completed in 1889.



This project was modified in 1910 to provide for dredging to 17-foot depth through the lake approach and 15 feet between the piers.

During the early years after completion of the project comparatively little maintenance dredging was required to remove the sediment deposited by the river during flood, an average of

but 5,000 yards annually having been so required during the first fourteen years.

Of late years, however, annual dredging has been required to maintain the project depth (except for a few years when commercial conditions did not appear to warrant it), from 20,000 to 70,000 yards being taken out each time. The increase of the shoaling is ascribed to the disappearance of the many logging dams and sorting works which were formerly on upper reaches of the river and which served as catch basins for the sediment which now has but little obstructed flow.

The entrance piers have, during late years, become badly decayed.

During a storm in the spring of 1921 the end of the east breakwater was carried away. No attempt has been made of late years to renew the wooden superstructure, and the funds available for maintenance would not permit the substitution of a concrete superstructure, even if the substitution were considered advisable. It is a question whether the old timber piers would be strong enough to withstand the added load of concrete, as the old timber cribs were not made as strong, nor with such care in dovetailing, as are the later ones. The temporary expedient has been adopted of placing heavy rock on top of the breakwater at those locations where the decking has become badly decayed, and of developing an entire rock superstructure by tearing down the walls of the old timber crib superstructure to water level, where it has become so badly decayed as to necessitate this treatment. It is still somewhat problematical as to what will ultimately be done at this location. As noted above there is some question as to the strength of the dovetailing of the side walls, and any outward thrust from the rock pile on top might sometime cause these to give way. Even though this should happen to the interior wall with the possible result of partly obstructing the channel it would not be very serious. In that event the rock at least would be on hand for use in the construction of a rubble mound should commercial conditions warrant it.

The marine commerce of the harbor is small, $126,313 in 1920, but the construction of a large pulp mill at the location points to a resumption of greater trade.

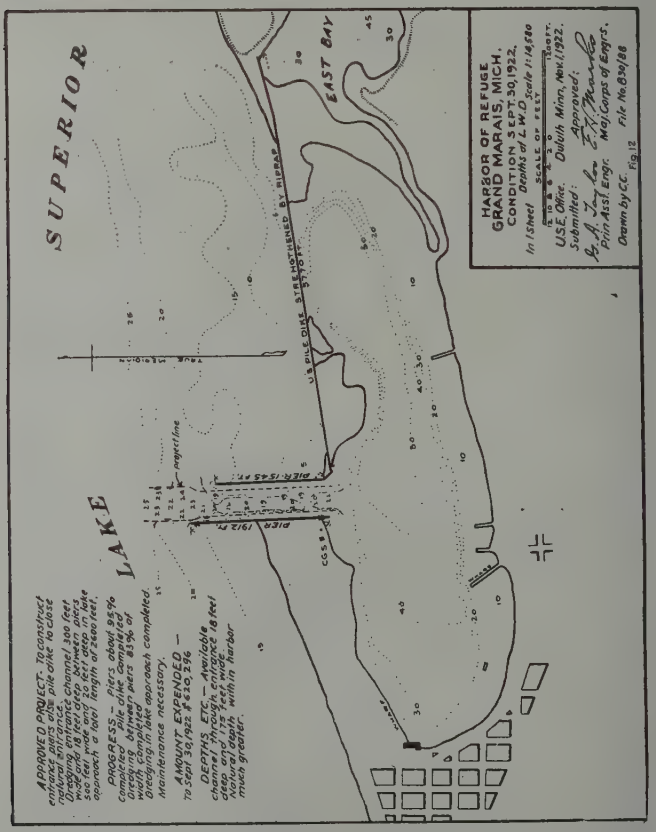
This harbor is of interest as representing the earliest form of pier construction on Lake Superior and as affording the only instance on the lake of an entrance channel maintained for a number of years almost entirely by the current of a stream, but little assisted by inflow or outflow from an interior basin. It is also of interest in view of the greatly changed conditions of silting since the inception of the project.

Grand Marais Harbor, Mich.

This harbor (Fig. 12), primarily a harbor of refuge, is situated on the south shore of Lake Superior, and is the only har-

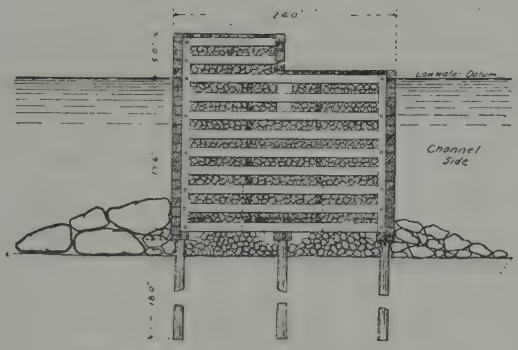
bor of any kind along this dangerous stretch of coast, 90 miles in extent, on which numerous wrecks have occurred.

Originally the harbor was a deepwater bay, well protected from storms, with an anchorage area of 240 acres and a depth of from 18 to 57 feet. The natural entrance, at the east end, was about 3,000 feet wide and was obstructed by a bar having a depth of 7 feet at low water.

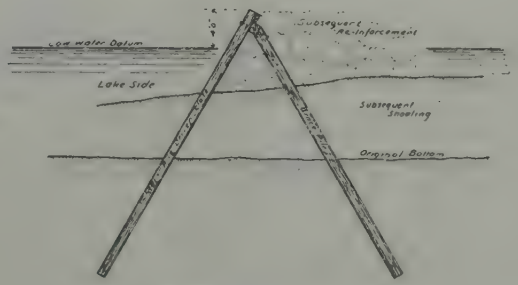

SUPERIOR
LAKE
EAST BAY
HARBOR OF REFUGE
GRAND MARAIS, MICH.
CONDITION SEPT. 30, 1922.
Depths at L.W.D. Scale 1:4,800
In 1 Sheet
SCALE OF FEET
U.S.E. Office. Duluth Minn. Nov. 1, 1922.
Submitted:
Approved:
Prin Asst. Engr.
Maj. Corps of Engrs.
Drawn by C.C.
File No. 830/88
Fig. 12
APPROVED PROJECT. To construct entrance and pile dike to close natural entrance, channel 100 feet wide and 18 feet deep between piers 500 feet apart and 20 feet deep between piers 500 feet wide and 20 feet deep in lake; dredging in lake approach completed.
AMOUNT EXPENDED to Sept 30, 1922 $210,296
DEPTHS, ETC. — Available channel through entrance 18 feet deep; natural depth within harbor much greater.
IN PROGRESS — Piers about 98% complete. Pile dike completed. Channel between piers 83% of dredging in lake approach completed. Maintenance necessary.
U.S. PILE DIKE STRENGTHENED BY RIPRAP 1921-22.
PIER 1912 FT.
PIER 1545 FT.
CRIB
CRIB
centerline

The project for improvement, adopted in 1881 and extended in 1894, provided for making a new entrance by cutting through the narrow sand spit separating the bay from the lake; constructing two parallel stone-filled timber-crib piers (Fig. 13) 500 feet apart, extending out to a depth of 22 feet in the lake; dredging a channel 18 feet deep between the piers and 20 feet

deep in the lake approach; and closing the shallow natural entrance by a dike formed of a single row of strongly braced piles in contact, driven so as to present an inclined surface to the waves. (Fig. 14). The expected formation of a sand beach along the line of the dike has been partially realized, but it was necessary after original construction to strengthen portions of the dike, still exposed to the heavy seas and damage by ice, by riprap.



GRAND MARAIS, MICH.
ENTRANCE PIER
SCALE 1 IN = 10 FT
Fig 13



GRAND MARAIS, MICH.
PILE DIKE
SCALE 1 IN = 10 FT
Fig 14

The works at this harbor are more subject to the action of drifting sand than are those at any other place on Lake Superior. As was foreseen when original study was made, the influence of littoral currents and of wave action in northwest storms causes

material to be moved along the shore in an easterly direction, and occasions shoaling in the lake approach and to a lesser extent between the piers, necessitating frequent maintenance dredging, usually annually. The extent of this movement of sand can be judged from the change in the shore line adjacent to the west pier which has since 1880 advanced 1020 feet.

To overcome in part this shoaling, and in connection with a proposal to provide a greater depth than that contemplated in the existing project, for the purpose of accommodating the larger class of vessels which have come into use of late years, there was proposed, in a re-examination report made in 1916, an extension of the west pier for a distance of 400 feet, and deepening the entrance channel to 22 feet. This project, which would probably lessen maintenance, and would make the harbor available for refuge for all classes of boats using the lake, has not yet been adopted by Congress.

It is of interest in this connection to note that, for the purpose of checking the bar formation, a proposal was made to construct a groin just east of the mouth of a sediment-carrying stream which empties into the lake about one and a half miles to the west of the harbor entrance. This proposal was, however, rejected. Experience, notably on Lake Erie, shows that the only sure and effective check to drift of this nature is by pier extension from time to time. A groin invariably causes erosion of the shore on its leeward (downstream) side with, in this case, possible increase of sand deposit at the harbor entrance and also erosion of private upland property.

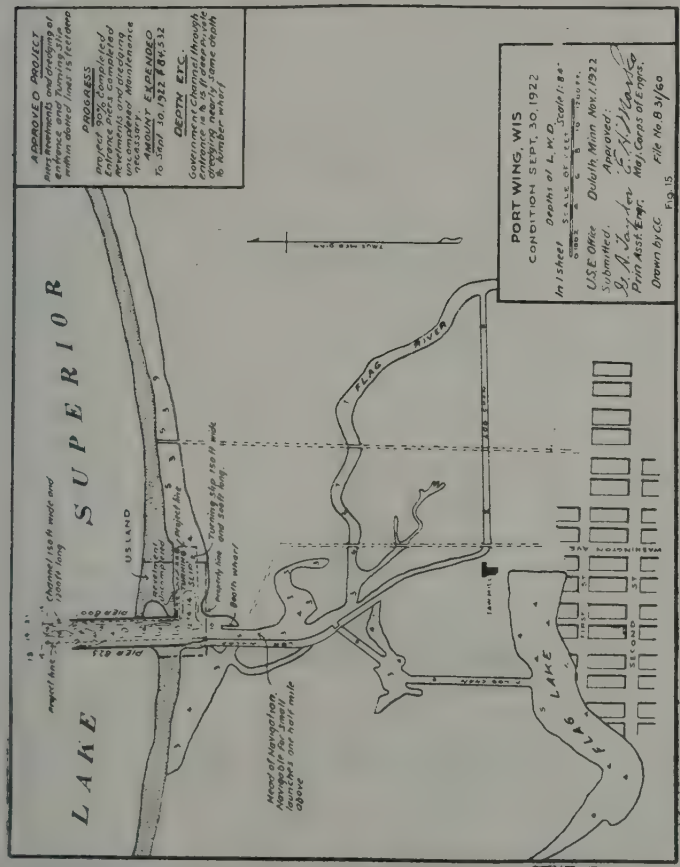
Port Wing, Wis.

What is known as the harbor of Port Wing (Fig. 15), lying on the south shore of Lake Superior about 34 miles east of Duluth-Superior Harbor, consists of a dredged channel into Flag River; a long, shallow body of water of varying widths, called Flag Lake; and several shallow sloughs which are separated from Lake Superior by long narrow sand spits. The original entrance through the sand spits sometimes closed up entirely during northeast storms, after which water would collect in Flag River and cut a channel through to a depth of 2 or 3 feet.

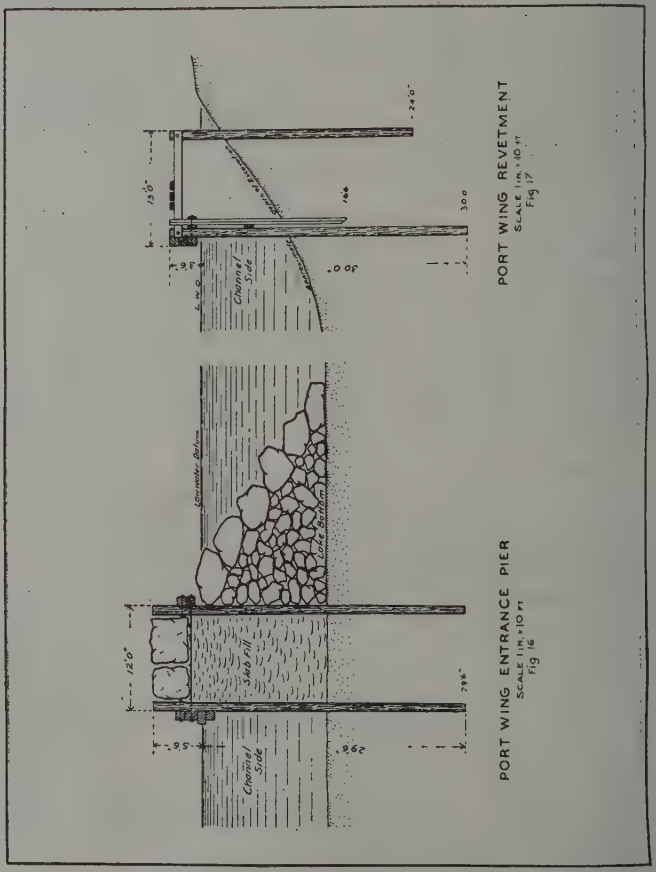
The enterprising citizens of the village of Port Wing had improved the entrance by building temporary pile piers, and kept it open for 13-foot navigation by dredging each spring for several years prior to 1903, when the Government assumed control.

The project adopted by Congress in 1902 provided for two parallel entrance piers 200 feet apart; dredging between them to a depth of 15 feet and width of 150 feet; and dredging a turning slip 150 feet wide, extending 500 feet easterly from the inner end of the east pier, and protected on the lakeward side by pile revetment to preserve the sand spit from erosion by an eddy.

The piers (Fig. 16) consist each of two rows of piling, close driven on channel side and on 5-foot centers on back side, 12 feet apart, waled and tied together, filled in with sawmill slabs and topped with large rock, and having an embankment of riprap against the exposed side in the deeper water but none in the channel.


PORT WING, WIS
CONDITION SEPT. 30, 1922
Depths at L.W.D.
In 1 sheet
SCALE OF FEET
USE Office
Submitted.
Approved:
Dulwth Minn Nov. 1, 1922
Maj. Corps of Engrs.
Dist. Engr.
Asst. Engr.
Drawn by CC.
File No. 8 31/60
Fig. 15
APPROVED PROJECT
PROGRESS
AMOUNT EXPENDED
To June 30, 1922 $84,512
DEPTH ETC.
SUPERIOR
LAKE
FLAG RIVER
USLAND
Pier 600 ft
Pier 600 ft
Head of Navigation
Navigable for small
boats one half mile
above
Turning Basin 150 ft wide
and 540 ft long.
Entrance Channel
Entrance Channel
Depth 18 ft
Depth 18 ft
Depth 18 ft

inner end of the west pier. It consisted of two rows of piles, 6 feet apart, cut off 6½ feet above water level and filled in with driftwood and rock ballast. The sea continued to cut around and under this wing revetment both from lake side and channel side so that it was dismantled and the west pier continued shoreward for a distance of 224 feet, giving the pier a total length of 825 feet.



The Port Wing project has never been completed, some dredging to widen the entrance channel and to enlarge the turning basin, and some revetment work remaining to be done. This additional work has not been justified by commercial conditions.

The piers require repairs from time to time due to natural

decay, wear of ice, and settlement of slab and stone filling, but on the whole are considered fairly successful, although their low height permits sand to be washed over the piers into the channel during storms.

The harbor entrance shoals quite rapidly from sediment carried down Flag River and also from material which is washed over the piers, and some dredging has been required annually of late.

A total of about $82,000 has been spent for construction and maintenance at this harbor while commerce during the last five years has had an average annual valuation of $150,000.

Class III.

Ashland, Wis.

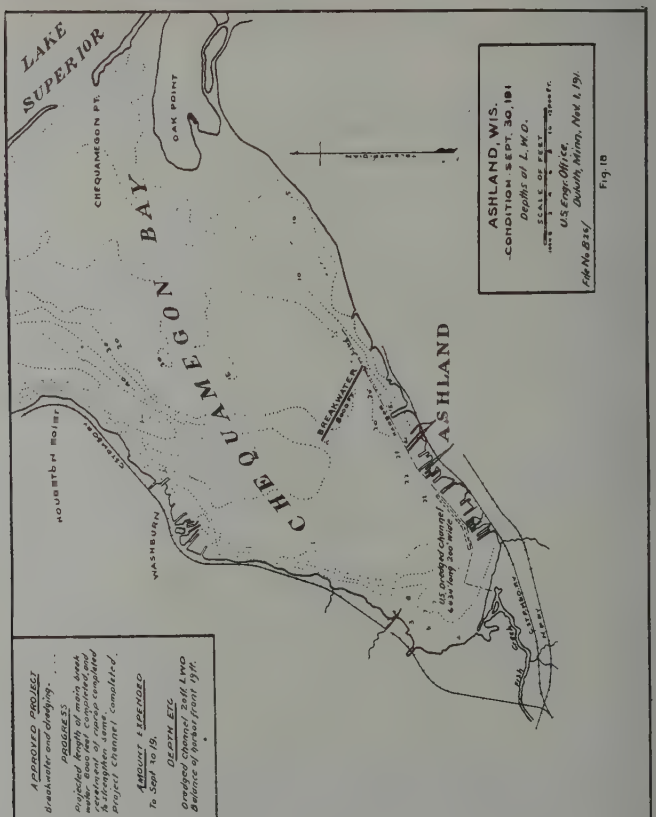
This harbor (Fig. 18) is located at the head of Chequamegon Bay, which is sheltered from the storms of Lake Superior by Chequamegon Point and the Apostle Islands, which latter protect the two-mile wide entrance channel between Chequamegon Point and the main land. The size of the bay, 5 miles by 12 miles, permits the generation within itself of heavy waves, which in northeast storms are augmented by the swell coming in from the lake, and which, before the construction of the protecting breakwater, made it unsafe for vessels to lie at the ends or on the exposed sides of the wharves. The natural depth at the entrance and through the bay up to the vicinity of the city is ample for lake navigation, but in proceeding to the southwest, shoaler water was found, which required dredging for the accommodation of large vessels.

The existing project provides for an 8,000-foot breakwater, terminating in a timber crib with concrete superstructure pierhead at outer end, and a dredged channel 20 feet deep, 200 feet wide and 6,434 feet long just outside a portion of the harbor line. The concrete superstructure (Fig. 20) was built without the use of footing blocks.

From motives of economy and because wave action was not so severe at this locality as at other points on the lake, it was decided to build the breakwater (Fig. 19) by driving a double row of piles about 18 feet apart, waling and tying same, and filling in the space between the piles with sawmill "slabs" to level of water surface, and weighting the "slabs" with heavy stones.

The cost of this breakwater was very moderate, about $17.25 per linear foot, but the form of construction has been frequently criticized on account of the high cost of maintenance due to decay of piling and tie timbers above water level, which if not quickly attended to would result in eventual destruction of the breakwater. However, in light of subsequent developments which indicated the advisability of constructing a rubble mound at this and other localities on the lake, the ultimate cost, with the use of the slab filled structure as a core for the mound, has been less by from $10 to $15 per linear foot than that of a com-

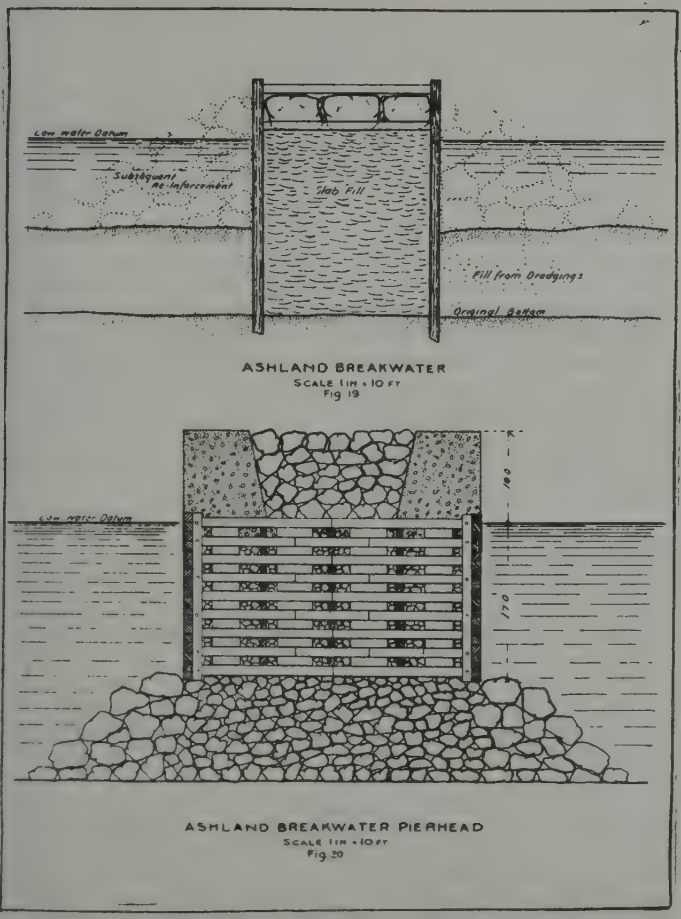
plete stone mound would have been at this locality. Of course with the departure of the sawmill from Lake Superior it would not at the present day be practicable to consider a slab fill core for a rubble mound.



In order to reduce the quantity of rock necessary for rubble mound the material from the dredged channel was deposited on either side of the old breakwater prior to placing of rock. During the process of converting the structure into a rubble mound, sandstone was used in places both for additional core and covering stone. Some of this sandstone has since worn considerably and disintegrated, necessitating the placing of rock. While some forms of sandstone can doubtless be used profitably for core, its use as a covering stone must be attended

with considerable caution for not only has it a less specific gravity than granite but is subject to wear and in some forms to rapid disintegration.

Breaches have occurred in the sand spit known as Chequamegon Point from time to time. There was formerly a project



to close these breaches with dikes but effort along this line was abandoned for the reasons that there could be no fear of permanent damage, as the same forces that built up the point would probably maintain it; that the closing of the breaches was objectionable to the authorities of the city of Ashland who claimed that the breaches gave a better circulation of water in the bay

from which the city water supply was taken; that the breakwater would amply protect the harbor and wharves from any disturbance caused by waves entering through the breaches.

Another project was one to extend the main breakwater to shore, subsequently modified to provide for a breakwater 4,700 feet long, parallel to, and 2,600 feet east of the main breakwater. This was never carried out as there was really no justification for it, ample room being available to the west of the main breakwater and under its protection for any and all probable future private improvements along the Ashland Harbor front. This breakwater was one which was never recommended by the district officer, nor by the Department at Washington. The authorizing act was due to the efforts of private parties in Ashand who had projects for improvement in that locality which would be benefited by such a breakwater.

The total cost of new work at Ashland has been $263,000 and for maintenance $378,000, the greater portion of the latter being chargeable to the breakwater as but little dredging is required at the locality to maintain the channel.

The work done at this harbor gives a protected area of about 1,600 acres, and affords safe anchorage and dockage for a distance of about three miles along the water front. The harbor is an important shipping point for iron ore from the Gogebic Range, Mich., and Wis. Its commerce for the last five years has averaged close to 10,000,000 tons per annum with average annual value of close to $35,000,000.

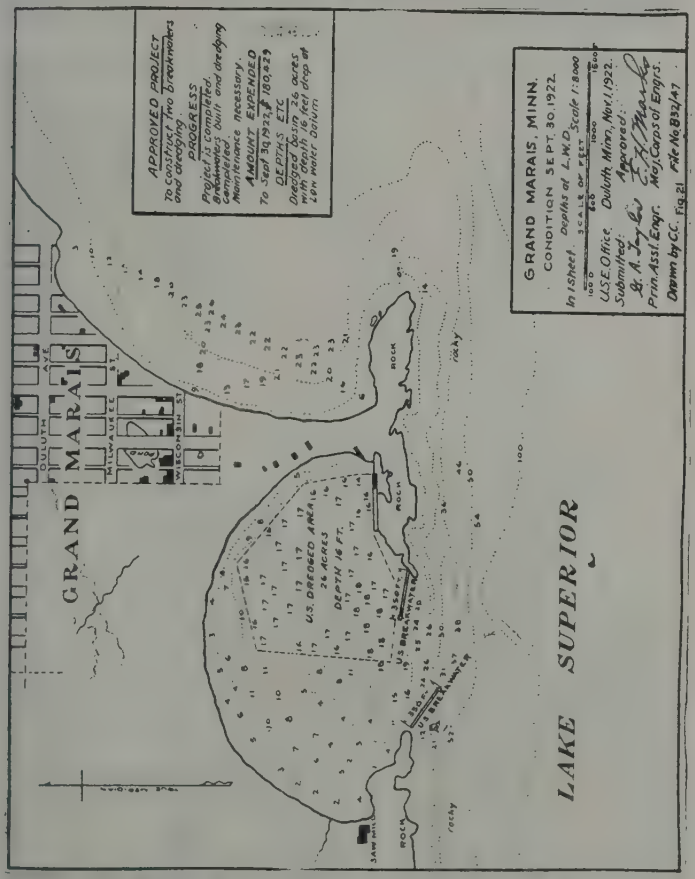
Grand Marais, Minn.

This harbor (Fig. 21) is situated on the north shore of Lake Superior, 106 miles northeasterly from Duluth. It is the only safe harbor on this shore between Agate Bay (or Two Harbors) and the international boundary, a stretch of about 126 miles of exposed coast.

Before improvement it afforded considerable protection to vessels of small draft, but it was much exposed to south and southwest storms. It had depths ranging from 12 to 16 feet over a very limited area and the general depths were from 4 to 12 feet.

The project, commenced by the United States in 1879 and completed in 1901, provided for dredging to a depth of 16 feet an anchorage area of about 26 acres, and for breakwater construction. The breakwaters, each extending out 350 feet from rocky points at either side of the harbor entrance, are of rock-filled timber cribs and have an opening of 480 feet between their ends. The east breakwater is of rectangular cross section, 40 feet wide, in the more exposed section, while the west breakwater is built with sloping face similar to that at Agate Bay (Fig. 23). There has been no maintenance dredging required, but the breakwaters have suffered through natural decay above the water line, and from wave and ice action.

A total of about $180,000 has been spent on this harbor to date while its commerce for the last five years has averaged $450,000 per year, consisting of fish, forest products and food

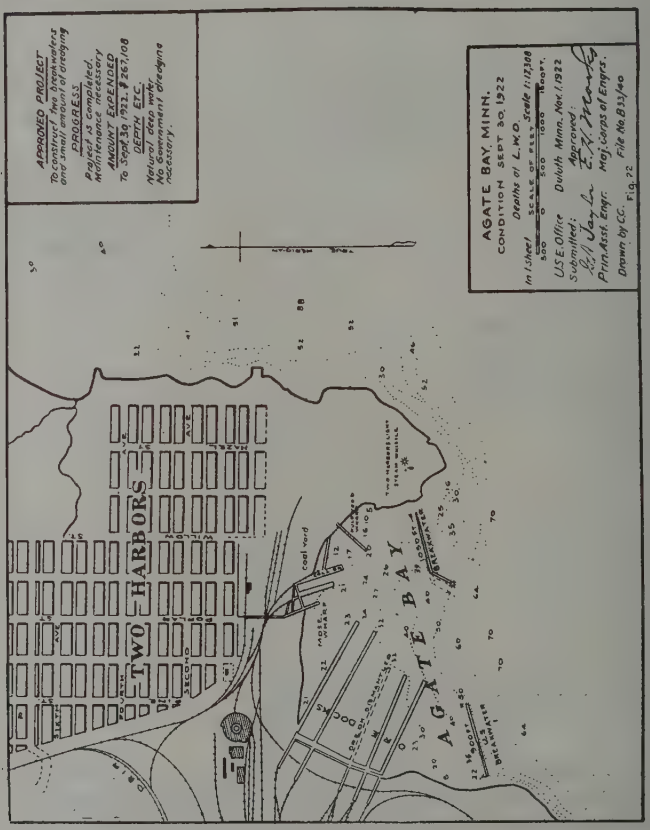

APPROVED PROJECT
To construct two breakwaters and dredging.
PROGRESS
Project is completed.
Completed: built and dredging
Maintenance necessary.
AMOUNT EXPENDED
To Sept 30 1922 $ 180,429
DEPTHS ETC
Dredged basin 26 acres with depth 16 feet drop at low water datum
GRAND MARAIS, MINN.
CONDITION SEPT 30, 1922.
In 1 sheet. Depths at L.W.D. Scale 1:8000
1000 0 1000 2000 3000 4000 5000 6000 7000 8000 9000 10000 Feet
U.S.E. Office. Duluth, Minn, Nov 1, 1922.
Submitted. Approved:
Prin. Asst. Engr. Maj. Corps of Engrs.
Drawn by CC. Fig. 21. File No. B32/47
GRAND MARAIS
DULUTH AVE
MILWAUKEE ST
WISCONSIN ST
U.S. DREDGED AREA 26 ACRES
DEPTH 16 FT.
U.S. BREAKWATER
LAKE SUPERIOR
ROCK
rocky

products. It also serves a very useful purpose as a harbor of refuge for small boats.

Agate Bay, Minn.

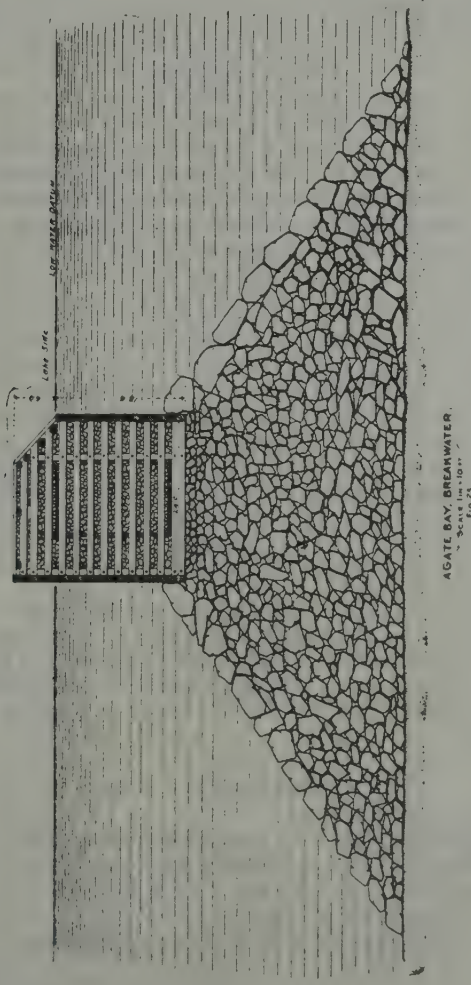
Agate Bay (Fig. 22), situated on the north shore of Lake Superior, 27 miles northeast of Duluth-Superior Harbor, is an important ore-shipping point for the iron mines of the Vermillion and Mesaba Ranges of Minnesota, and besides other less important commercial purposes, is used as a harbor of refuge.

It was originally a natural harbor with deep water at the entrance and throughout much of its extent of 109 acres. It was, however, directly exposed to winds from southeast through south to southwest and to heavy swells from southwest storms and reverse swells from severe northeast storms.



The work of improvement was commenced by the United States in 1887 under a project providing for the construction of two breakwaters, one on each side of the entrance to the bay, with a clear opening of 1,300 feet between their outer ends, and a gap of about 100 feet between the inner end of each breakwater and the rocky shore adjacent, the purpose of the gaps in the shallow water being to save in cost. The project also provided for a small amount of dredging to 18 feet.

The east breakwater extends about S. 75° W., for 750 feet and thence S. 30° W. for 310 feet. The west breakwater extends about N. 75° E., for 900 feet. Both breakwaters are built of



stone-filled timber cribs, (Fig. 23), 24 feet wide, resting on an embankment of riprap, the top of which is 18 feet below low-water datum. The deck of the superstructure is 6 feet above the

water level. The east breakwater terminates in water 55 feet deep, the greatest depth in which any construction of this character has been attempted on Lake Superior. These breakwaters were completed in 1901 at a cost of about $234,000.

There are in the harbor four large ore docks, a coal dock, pulpwood wharf and two other small docks. These docks together with the slips between them occupy so much of the available area that there is scarcely room for vessels to enter and make the turns in and out of the slips, and no space for anchorage. In consequence, the breakwaters have been repeatedly struck by vessels, and in some instances considerably damaged. Costs for repairs in such cases are, as is customary, assessed against the owners of the vessels causing the damage.

The breakwaters have withstood well the action of waves although there has been deterioration due to natural decay and wear of ice. Iron sheathing one-fourth inch thick and 3 feet wide has been placed to prevent wear of ice at the water line and serves its purpose. It will be necessary before many years to renew the superstructure. Owing to the great depths involved and limited space within the harbor, it will probably be impracticable, on account of cost, to construct a rubble mound, as is being done at other harbors, and some form of concrete superstructure will probably be adopted.

As there is no littoral deposit and as no sediment-bearing streams enter the harbor there has been no necessity for maintenance dredging. The approaches to the ore docks are naturally sufficient for 21-foot navigation, and necessary private dredging in the slips between docks to provide for 20-foot navigation has been done.

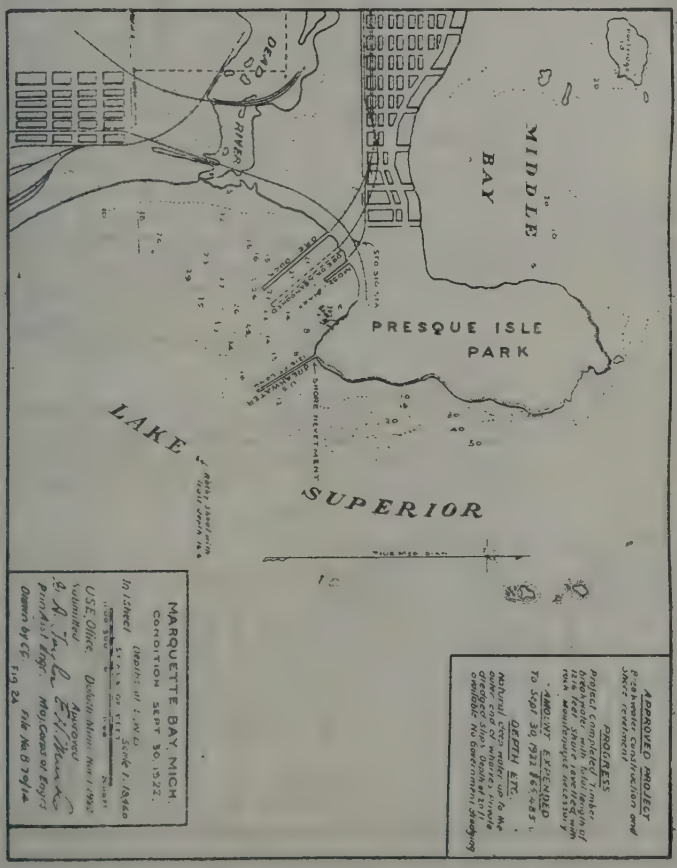
The vessel freight of this harbor has increased from 264,320 short tons valued at $524,800 in 1885, to a maximum of 12,349,278 short tons valued at $33,255,952 in 1916, and has remained close to that figure. This little harbor is well within the first twenty harbors in the United States in amount of freight handled.

Marquette Bay, Mich.

This harbor (Fig. 24), also known as Presque Isle Harbor, and officially though erroneously known as a harbor of refuge, is an indentation in the shore 3 miles north of Marquette Harbor, and just south of Presque Isle Point, by which it is protected from northerly and, to some extent, from northeasterly storms. Further protection is afforded by the breakwater built under a project of 1896 and modified in 1902. It is used principally as a shipping point for iron ore from the Marquette Range.

The breakwater, which is constructed on a reef projecting out from shore in a general southeasterly direction, was origi-

nally 1,050 feet long and began at a point 120 feet from shore. It is a stone-filled timber-crib structure (Fig. 10) and is noteworthy on account of its triangular section above water. During the season of 1902, the gap at the shore end of the breakwater, which had been widened by the action of waves, ice and currents, was closed by stone-filled timber-crib work and a rock revetment was later placed at the shore end to prevent erosion

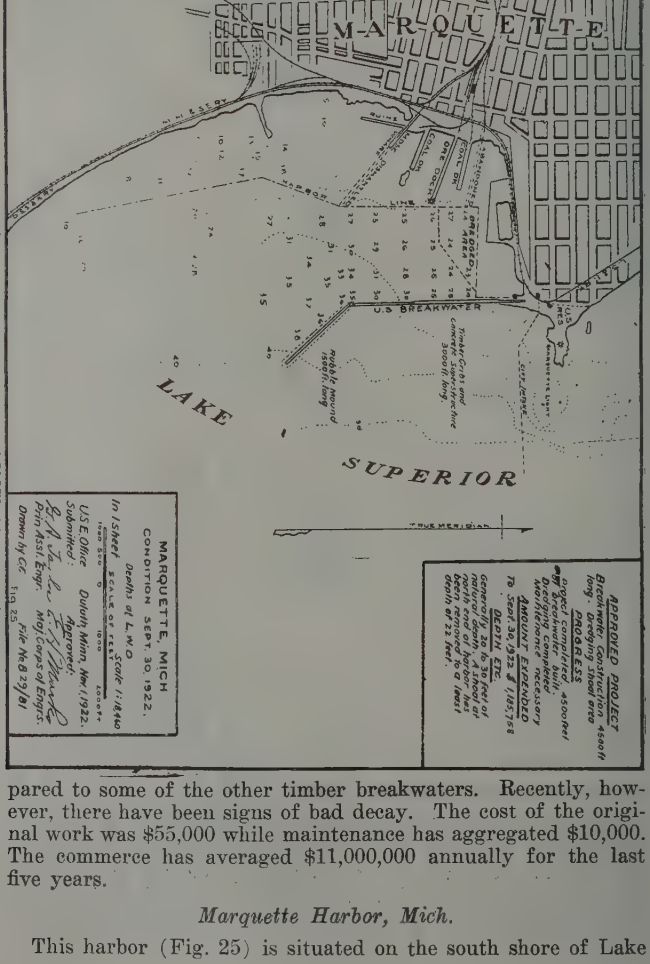


of the sand bluff. No government dredging has ever been required.

The breakwater affords considerable protection to the harbor, so that vessels can lie at the wharves and load during moderate storms, but during severe storms they have to run to Marquette for safety.

There is no particular reason for a harbor at this locality other than as an adjunct to Marquette Harbor. The combined terminal facilities of the two would, if concentrated in Marquette Harbor, probably cause serious congestion there.

The breakwater was built at a comparatively small cost and has required comparatively little maintenance to date, as com-

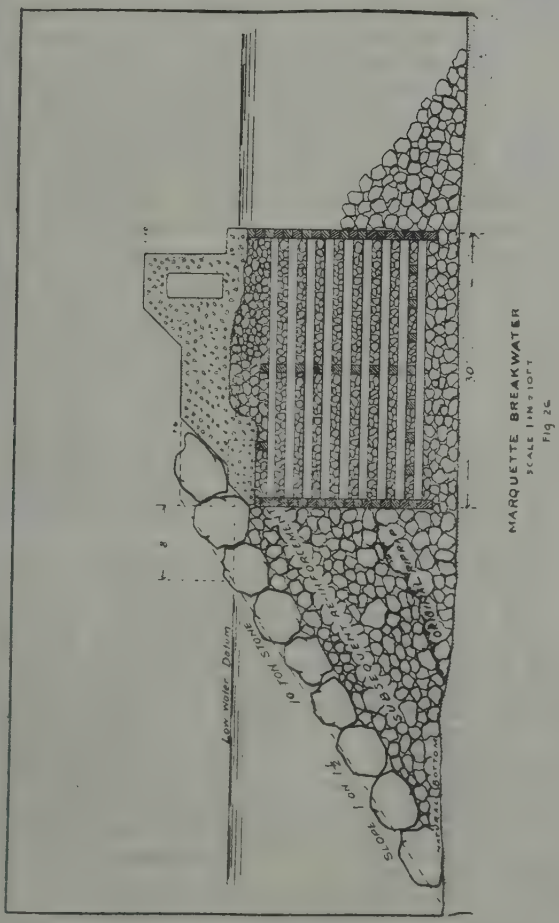


pared to some of the other timber breakwaters. Recently, however, there have been signs of bad decay. The cost of the original work was $55,000 while maintenance has aggregated $10,000. The commerce has averaged $11,000,000 annually for the last five years.

Marquette Harbor, Mich.

This harbor (Fig. 25) is situated on the south shore of Lake

Superior, 160 miles west of Sault Ste. Marie, Mich., and 256 miles east from Duluth, Minn., and is an important shipping point for iron ore from the Marquette Range and receiving point for coal for use on the range and other activities of the locality. It orginally afforded no protection to vessels from northeasterly



or easterly storms and the slight protection afforded by the shore indentation allowed only a precarious landing for vessels. There were no defined channels and the minimum usable low-water depth was 17 feet.

The work of improvement was commenced by the United States

in 1867 under a plan providing for the construction of a stone-filled timber crib breakwater 2,000 ft. long. This was subsequently extended 1,000 ft., and still later was further extended by the addition of a 1,500-foot rubble mound structure which, together with the dredging of a small shoal area, gave a total protected area of 350 acres.

The stone-filled timber superstructure (Fig. 26) of the old breakwater, with the exception of 90 feet at its outer end, was replaced during the years 1895 to 1904 with concrete, rising 10 feet above low water. Footing blocks, cast ashore, were used in the superstructure. These were placed along the edge of the cribs, but as the latter were not in perfect alignment, the mass of the superstructure did not in all places overlap the footing blocks sufficiently to give requisite stability, and some of these blocks were dislodged in storms. To prevent future damage a plan was adopted to place the breakwater in practically permanent form by placing riprap along the lake face. This plan had been adopted at other concrete-capped breakwaters on the Great Lakes, especially those having low sloping aprons along the lake front. The 90 linear feet of timber crib superstructure which was not converted into concrete superstructure was cut down to water level in 1922 and covered with riprap.

The rubble mound extension (Fig. 6), which was provided to afford more complete protection for the vessel commerce, was built at an angle to the existing breakwater primarily for the reason that it would permit of further extension in the same direction in case of additional protection being needed at some future time.

The lake front of the rubble mound extension on the outer 700 linear feet was damaged by storm in November, 1917. The surface rock was disturbed at many points and carried down on the lake slope below water, and a considerable quantity of core stone was also moved. At three different points large covering stones, weighing not less than 10 tons, were thrown from their positions in the superstructure to the crown of the rubble mound. This damage was not so serious as to greatly reduce the effectiveness of the breakwater, but to guard against loss of core stone, repairs will be required to restore original grades.

A total of about $1,150,000 has been spent on the project at Marquette. The commerce has averaged in excess of 1,000,000 tons during the past five years with an average value in excess of $6,000,000 per annum.

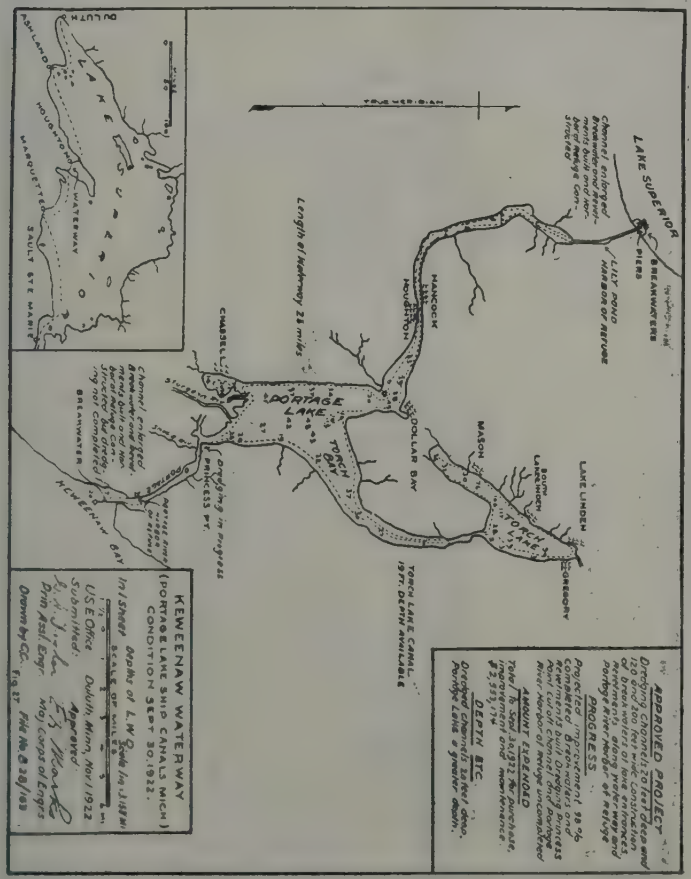
Class IV.

Superior Entry, Duluth-Superior Harbor.

This has been described above and will not be further discussed.

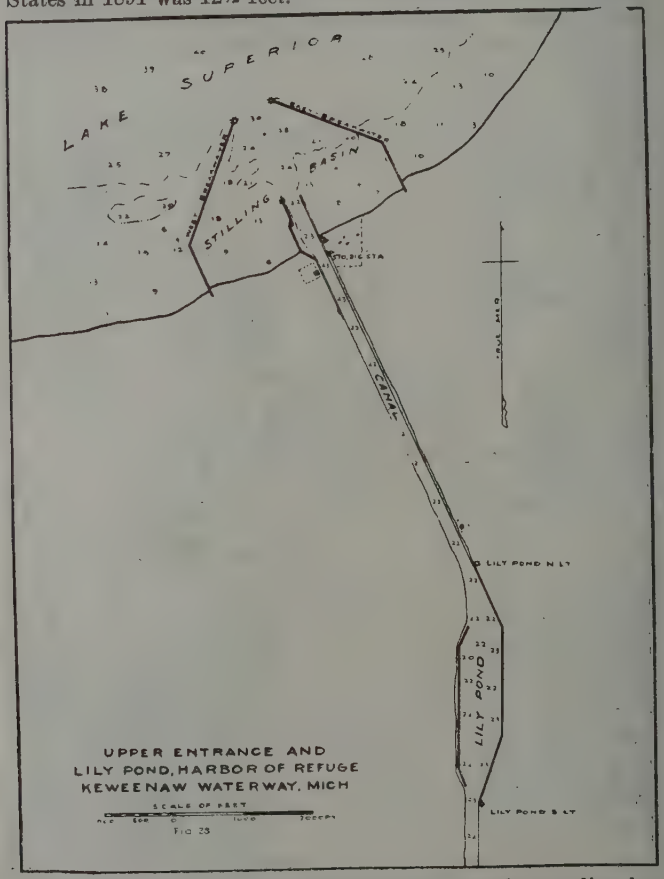
Keweenaw Waterway, Mich.

This waterway (Fig. 27), formerly designated the Portage Lake and Lake Superior Canals, Mich. is about 25 miles in length, crossing Keweenaw Peninsula from Keweenaw Bay on the southeast side to open lake on the northwest side, including



5 miles in Portage River and its dredged cuts, 17½ miles in the naturally deep Portage Lake, and 2¼ miles in the upper canal from the head of Portage Lake to Lake Superior, excavated through what was formerly dry land at the northerly end of the route. It was originally constructed by a private corporation for the purpose of affording a through route for vessels bound up and down the lake, with refuge from storms, and of develop-

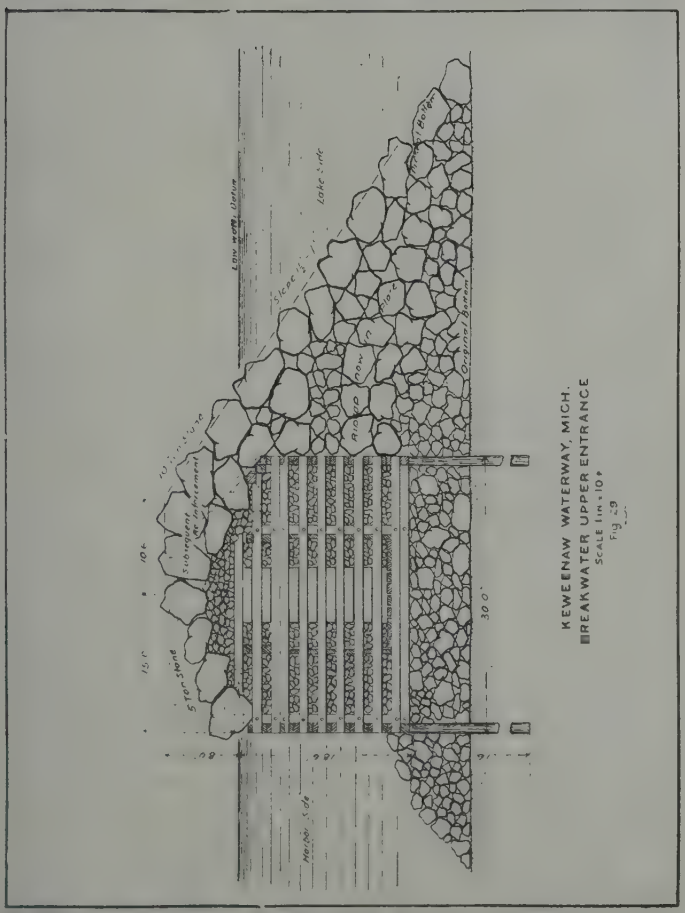
ing the commerce of the rich copper mining territory adjacent to Portage Lake. The available depth of Portage River prior to improvement was 3 to 4 feet, while the general channel depth throughout the waterway when it was purchased by the United States in 1891 was 12½ feet.



This canal provides no shorter route for vessels traveling between Sault Ste. Marie and Duluth but affords a short saving between Marquette and Duluth, and Marquette and Houghton. The waterway is, however, considerably used for refuge aside from its use in local traffic.

The existing project provides for a navigable channel 20 feet deep with least bottom width of 120 feet and with necessary

revetments of pile and timber in the canal and in the cuts of Portage River; a stone-filled timber pier at the lower entrance, 3,700 feet long, extending to 20-foot depth of water; converging stone-filled timber piers at the upper entrance; an upper entrance anchorage basin 3,450 feet long by 600 feet wide, with 5,924 feet of pile timber mooring piers; and an anchorage basin



at the lower entrance ½ mile long and 800 feet wide, with a pile timber mooring pier 2,000 feet long.

A recent modification provides for excavating a broadly curving channel across Princess Point with length of about ¾ mile and depth of 20 feet for a bottom width of 200 feet, to do away with a very sharp turn in the Portage River at that point.

At the Upper Entrance (Fig. 28) storms are more severe and frequent than at any other point under improvement on Lake Superior. Consequently, it was decided to form an artificial harbor there which would afford refuge during storms and would facilitate the entrance of vessels into the canal in rough weather, as but little protection was afforded by the old parallel timber piers which had been built by the canal company. This was accomplished by the construction of two stone-filled timber-crib breakwaters, completed in 1901, each about 2,700 feet in length. They start at the shore line about 3,000 feet apart and extend out at right angles to its general direction for about 800 feet. Each is then deflected about 45° toward the other and extends in the new direction about 1,900 feet, terminating in water 31 feet deep, and leaving a clear opening 400 feet wide at their outer ends through which vessels enter. The opening is 2,000 feet from shore. The partially sheltered area of 106 acres, inclosed by the breakwaters, has a depth varying from shallow water along shore to 31 feet at the entrance, about 39 acres of the area having a least depth of 18 feet and affording anchorage with fair shelter.

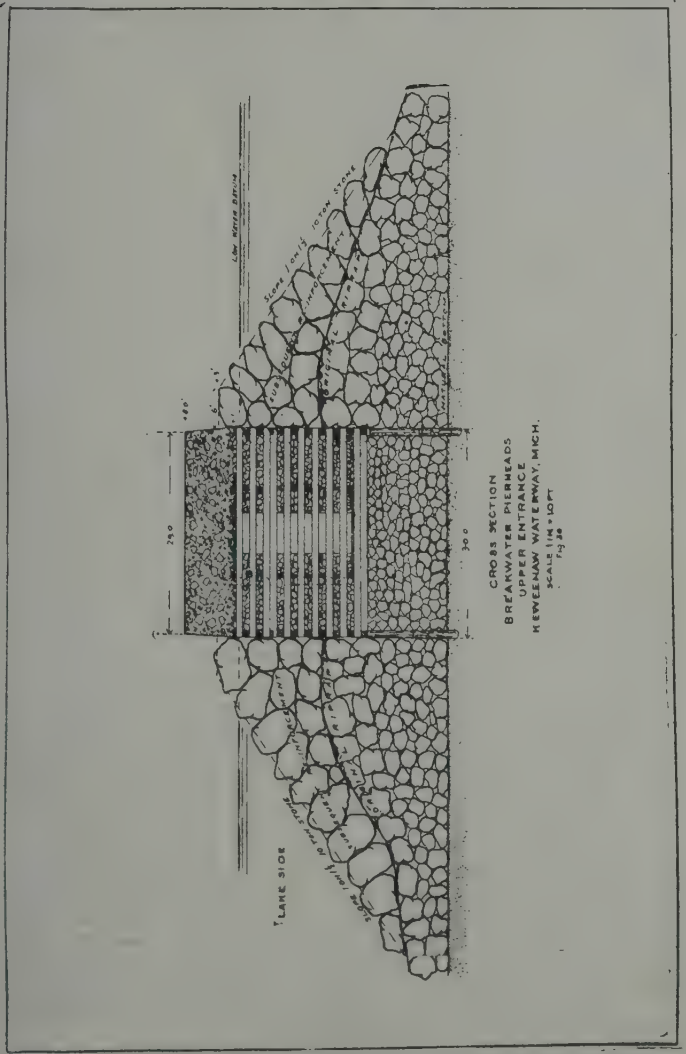
The natural decay of the timber above water level combined with ice and wave action has resulted in extensive deterioration of the super-structure, and in order to maintain the piers a plan has been adopted to remove the timber superstructure to water level, and replace it with rubble superstructure and riprap on the lake side (Fig. 29). It will be noted that the crest of the mound has been placed over the outer wall of the crib. This has been done to lessen the chances of collapse of the inner wall under the heavy weight and wave action.

Originally there was at the outer end of each breakwater a return or arm 100 feet in length built at right angles to the direction of the main breakwater and extending inward toward the harbor. For the reason that these arms, or L's, served no useful purpose, but on the contrary restricted the width of opening, and because they had been undermined to some extent by wave action at the base of the timber cribs, the L's were removed by dredging, and a pierhead substituted (Fig. 30), consisting of a concrete superstructure on the timber crib, reinforced with riprap. Footing blocks were not made use of in the construction of the superstructure.

The pier at the lower entry is a stone-filled timber-crib structure with sloping face, 3,714 feet long, completed in 1899. There not being excessive wave action at this locality there has been but little damage to the pier other than ordinary decay above water level. This pier is noteworthy as it provides an example of a dredged channel maintained by a single structure fulfilling the double functions of a breakwater and of a pier.

The entire cost to the United States of the waterway is a little in excess of $2,000,000. Through commerce, or that using the

waterway for shelter has averaged about 500,000 tons annually of late with average value of something over $40,000,000, while local commerce averages about 1,300,000 tons with value of from



$30,000,000 to $40,000,000. The improvement at Princess Point will doubtless increase the number of vessels using this waterway as a refuge.

PROGRESS AND CHANGES IN MATERIALS AND DESIGN OF PIERS AND BREAKWATERS ON LAKE SUPERIOR.

Foundations.—Piers of the older type were constructed by excavating a trench, making its bottom as nearly level as practicable, and sinking cribs on the bottom thus prepared.

As a result of unequal settlement, erosion of the bottom alongside the pier, or of removal of material from beneath the cribs by cross currents, displacement of the cribs sometimes resulted, and especially was this the case where the bottom was very sandy or where the original channel depth had to be increased to meet the demands of commerce.

To avoid this trouble the piers planned or constructed on Lake Superior in later years are supported upon a foundation of piles sawed off at, or near, the bottom. Such a form of construction prevents lateral or vertical displacement of the cribs from the causes mentioned, and has proved preferable to the use of fascine mats, which were tried with only partial success at Grand Marais, Mich., and were afterwards abandoned in favor of a pile foundation.

Due to advance in cost of timber, and to the low cost of rock, motives of economy rendered it necessary that in water of considerable depth, as at Agate Bay, the cribs of breakwaters rest upon a rubble mound, flattened and leveled on top. With known depths of water, and the widths of crib established, the most economical cross section of breakwater can readily be computed from unit costs of cribs and rock.

To prevent unequal settlement, which is always likely to occur in breakwaters when the cribs rest upon a stone embankment, the cribs may rest upon piles, as at the Upper Entrance, Keweenaw Waterway, the stone embankment extending to the level of the top of the piles. This method of construction proved very successful in that case, but would be attended with much uncertainty if the length of piles above bottom were too great.

Cribs.—During the period in which cribs were generally used the tendency in their design was toward increased strength and greater length, decrease in size of timber ties, which originally were unnecessarily large, and increase in thickness of decking, which is severely tried by wave action. As a means of protection against ice, rafts and vessels, steel plating was used on the cribs; and in order to retard decay, air spaces were left between adjacent deck planks. A very important modification from the earlier structures is the adoption of a sloping face on the exposed side. This change tends to reduce the strain upon the superstructure and especially the deck by causing a portion of the wave energy to be expended in lifting a mass of water, and projecting it in an inclined direction above and over the deck of the breakwater. As a result practically no water falls normally upon the deck during storms.

Pile and slab type of breakwaters and piers.—Even if the sawmill had not almost disappeared from Lake Superior it is unlikely that a rock-weighted "pile and slab" type of breakwater

would ever be used again on the lake, as it is expensive to maintain and does not withstand well the attack of waves. This form of construction was used at Port Wing on account of limited funds, because the exposure is not great and the general direction of wave travel is parallel to the piers. These piers were so planned that waling timbers and other strengthening timbers are, so far as practicable, below water level and therefore not subject to decay. Heavy riprap was also used along the exposed side to give additional strength.

Materials.—Until 1897 or 1898, timber and stone were the two materials of which all breakwaters and piers on Lake Superior were constructed. Their universal use arose from three reasons: (1) the abundance; (2) the cheapness; and (3) the ease with which timber cribs could be built in sheltered localities, partly weighted with ballast, and then towed to their proper places and sunk. Owing to the exhaustion of the immense pine forests adjacent to the Great Lakes, it has been practically impossible, for fifteen or twenty years, to obtain native timber of necessary dimensions in the vicinity of Lake Superior, and such large timber as has been used in this period has been procured from the Pacific Coast, over 2,000 miles distant. It was early seen that timber superstructures would require complete renewal at intervals of from twelve to fifteen years. The decrease in cost of cement and increase in cost of timber has led to the use of concrete, for replacement of superstructure, as at Marquette, Mich. Although concrete has since been frequently used on Lake Superior in pier construction, it has not been used in other localities than Marquette in breakwater construction, except for pierheads. The more recent breakwater construction and renewals have been of rubble mound or modified rubble mound type. At such localities the depths have not been excessive, but at a locality such as Agate Bay, where excessive depth exists, consideration will undoubtedly be given to some form of concrete superstructure.

In pier construction there are the examples of timber-crib stone-filled substructure with concrete superstructure at Duluth Canal—besides several pierheads on breakwaters. There are also the entire concrete piers of Superior Entry which were adopted after a study of the relative merits of this form and the timber-crib type. The submerged weight of a crib such as in the Duluth Canal is about 50 lbs. per cu. ft. while the submerged weight of concrete is 87 lbs. per cu. ft. It is therefore evident that for equal stability against overturning or against displacement by waves, the area of cross section of a concrete pier would be considerably smaller than in the case of one of crib work. Although it is quite probable that, except for construction difficulties caused by storms and ice, a pier entirely of concrete could be built at the present day for less than one of the crib and concrete type, the former method of construction would doubtless be impracticable in an exposed location except at prohibitive costs.

At the time of building the Superior Entry piers the concrete-caisson type of breakwater had not been generally used, but in any new works proposed for Lake Superior, especially pier construction, this type of structure would be given most careful consideration.

On about one-half of the Marquette breakwater, all of the Superior Entry breakwater pierheads, and all of the Duluth Canal piers, footing blocks were built on land and later put in place, thus avoiding the necessity of placing green concrete in water. On the other works of the district the concrete superstructures were placed in from 0 to 2.0 feet of water.

Where footing blocks were cast ashore and put in place no deterioration has occurred as a rule. In the case of the Marquette breakwater a few footing blocks show deterioration, attributed entirely to action of frost when the blocks were cast, and before they were put in place in the breakwater. At Duluth Canal piers no deterioration has taken place other than a slight spawling at the joints between blocks, due to their lateral movement in time of storm.

At Superior Entry the south pier superstructure was built in 1904-05 and the north pier superstructure in 1907 and 1909. All the south pier and the portion of the north pier built in 1907 shows some raveling of the concrete from low-water datum to about one foot above low-water datum. In the case of both piers some washing of cement from the concrete was noted when the forms were taken off. This was due to the motion of the water, caused by passing vessels and by waves, when the concrete was fresh.

On work done at Superior Entry after 1907, cotton cloth was tacked to the bottom of the forms and spread out on the substructure to keep the wash of the water from the fresh concrete. Prior to that time burlap or concrete in burlap bags was used for the same purpose. The burlap was not effective. The work done after cotton cloth was used in 1907 shows no deterioration. The demarcation between work done in 1907 with burlap stopwater and work done on the same pier in 1909 with cotton cloth is striking and shows that a closely woven cloth is effective in protecting fresh concrete from the surface motion of the water.

At certain localities on Lake Superior pebbles are very abundant and of excellent quality. The sizes are generally so nicely assorted by nature that the percentage of voids is smaller than in the case of broken stone, and consequently, less cement mortar is required to fill the voids. At equal prices per unit for all materials, concrete of pebbles is therefore cheaper than that of broken stone, and as gravel costs less per cubic yard on Lake Superior than broken stone, the latter has been but little used on Government work in the vicinity of the lake.

Width of entrance between piers.—In the older works, the width of entrance channels varied from 250 feet at Duluth Canal

to 500 feet at Grand Marais, Mich. In the former case the width was scarcely sufficient to permit large steamers to pass one another readily, while in the latter case the entrance is so wide, as compared with the area of the interior basin, that the currents, which are developed solely by fluctuations in lake level, are not sufficient to render the channel self-sustaining. In fixing the width of entrance channels on Lake Superior there is invariably a conflict between two opposing considerations. For ease of ingress and egress of vessels, a wide channel is desirable. To reduce the disturbance caused by swells which enter the harbor, a channel should be as narrow as possible.

After due consideration and as a compromise between the conflicting conditions, the width of channel at the Duluth Canal was fixed at 300 feet, and the project for rebuilding the Superior Entry calls for the same width. While the work at Superior Entry was in progress a severe storm occurred, during which fourteen vessels were wrecked in the west end of Lake Superior. Two of these vessels were sunk due, at least in part, to injuries sustained by striking the piers of the Duluth Canal while trying to enter the harbor. Some damage was also incurred within the harbor from waves entering through the canal. So far as safety to navigation is concerned the experience upon this and other occasions indicated a desirability of greater entrance width than 300 feet. On the other hand, an increased entrance width would cause greater disturbance in the inner harbors due to the admission of waves.

These considerations led to a modification being made in the Superior Entry project, providing for shorter piers with a width of 500 feet between them, and the construction of the wave stilling basin described above. Owing to the great area of the interior basin as compared to that at Grand Marais, Mich., it was expected that the channel would be self-sustaining, which has proved to be the case.

Owing to the fact that the Duluth Canal was constructed so near the extreme north end of Superior Bay, the swells which enter the bay through the canal have but little room toward the north in which to expand, and consequently, cause some inconvenience in this vicinity for short periods during severe storms. This trouble would have been avoided had the City of Duluth cut the canal 3,000 or 4,000 feet south of its present location.

Superstructure tunnels.—The tunnels provided in the superstructures at Duluth Canal and Marquette were provided with two ideas in view—one to save concrete—and the other to provide protected passages to pierhead lights for use during storms. Due to wearing of the expansion joints between monoliths, permitting the entrance of water during storms, these tunnels are not serviceable for the passage of persons at such times. It is believed, furthermore, that the cost of providing the special forms needed for these tunnels overbalances any saving in cost of concrete.

GROWTH OF COMMERCE ON LAKE SUPERIOR AND ECONOMICS OF THE HARBOR IMPROVEMENTS.

The growth of marine commerce on the Great Lakes has been enormous, and especially remarkable has been the development on Lake Superior. In 1883 the total amount of freight passing through both the United States and Canadian canals at Sault Ste. Marie, which is an accurate measurement of the volume of through vessel freight on Lake Superior, aggregated 2,267,105 short tons. In 1893 this freight had increased to 10,796,572 tons; in 1903 it had increased to 34,674,437 tons; during the period 1907-1921 the average annual tonnage was 74,254,303 tons, of which about 93 per cent. was carried in American vessels.

The development of this immense lake commerce has been rendered possible by Government improvement of the harbors of the Great Lakes and of the waterways connecting them.

In 1883 the governing low-water depth in Duluth-Superior Harbor was but 12 feet, while at Sault Ste. Marie it was 14.5 feet. At the present time the governing depth at the six principal improved harbors on Lake Superior is 20 feet. On the waterways connecting the Great Lakes the governing depth is the same.

The increase of depth, obtained by means of Government improvements, has had a marked effect upon transportation methods and has resulted in a steady increase in the size of vessels, and consequently, in the carrying capacity. In 1883 the average cargo carried by vessels passing through the Sault Ste. Marie canals was 473 short tons; in 1893 it was 899 tons; in 1903, 1,865 tons; and in 1921, 3,756 tons. The latest and largest type of lake ore carriers are the Steamers "Wm. P. Snyder" and "Col. James M. Schoonmaker," which have an over-all length of 617 feet, 64-foot beam, and 33-foot molded depth. These ships can each carry in excess of 15,000 short tons. There are many other vessels in service which closely approach these two in size and capacity.

With increase of depth and growth of commerce equal progress has been made in improving facilities for handling bulk freight, until at the present time vessels are loaded and unloaded on the Great Lakes with a rapidity unequaled elsewhere; for example, a cargo of 12,500 long tons of iron ore was loaded on a vessel in Duluth-Superior Harbor in 16½ minutes. Vessels carrying from 10,000 to 11,000 long tons of coal are unloaded in the same harbor in periods of from seven to eight hours; while at lower lake ports the same quantities of iron ore are unloaded in from three to four hours.

When the depths were small and the carrying capacity of vessels limited, vessel owners endeavored to compensate for limited carrying capacity by employing steamers to tow one or more barges or schooners. In 1870 the number of schooners, barges, etc., passing through the canals at Sault Ste. Marie, was

more than three times greater than the number of steamers; in 1880 the two classes of vessels were equal in number. At the present time there are no sailing vessels and but few barges in service on the Great Lakes. The relative number of large vessels in service can be judged from the following table, which shows the percentage of the total freight carried by each class of vessels in service:

Tons—Net registered	Percent of total freight carried by class
3,000 to 4,000	17
4,000 to 5,000	29
5,000 to 6,000	30
6,000 and over	12

The present policy in interlake transportation is the use of single carriers of large capacity and moderate speed constructed with numerous hatches to facilitate loading and unloading.

Due to increased depth, to the resulting increase of the capacity of vessels and to improved facilities for handling bulk freight, there has been a steady but somewhat irregular reduction of freight rates on the Great Lakes. In 1887 the average haul for all freight passing through the Sault Ste. Marie canals was 811.4 miles and the average freight charge per ton per mile was 2.3 mills. In the period 1917-1921 the average haul was 811.5 miles and the average freight charge per ton per mile was 1.18 mills. Notwithstanding the low freight rate, average annual freight charges amounting to $72,069,891 were paid in the period 1917-1921 upon the total freight passing through the canals at Sault Ste. Marie. The following table shows the freight movement since the commencement of improvements by the United States and also the total cost of harbor improvements up to January 1, 1922:

NAME OF WORK.	Date of commencement of improvements by the U. S.	Vessel freight from commencement of work to Jan. 1. 1922.		Total amount expended on improvements, operation and maintenance up to Jan. 1, 1922.
		Tons of 2,000 lbs.	Estimated value.	
Grand Marais, Minn..	1880	488,467	$ 16,138,141	$ 179,813
Agate Bay, Minn..	1887	207,686,446	600,715,476	266,674
Duluth-Superior, Minn. and Wis..	1867	808,369,791	7,937,808,168	8,228,932
Port Wing, Wis..	1903	476,998	7,119,730	83,268
Ashland, Wis..	1887	159,949,121	833,781,977	641,303
Ontonagon, Mich..	1867	2,907,863	77,228,339	500,866
Keweenaw Waterway, Mich..	1891	54,298,373	1,963,058,769	2,497,049
Marquette Bay, Mich..	1897	46,371,039	144,822,354	65,143
Marquette, Mich..	1867	43,239,018	220,979,879	1,140,648
Grand Marais, Mich..	1880	1,515,389	28,206,756	611,451
Total.		1,325,302,505	$11,829,859,589	$14,215,447

It will be seen from this table that up to January 1, 1922 the sum of $14,215,447 had been spent upon the improvement, maintenance and operation of the United States harbors on Lake Superior, and that during the same period the vessel freight handled at these harbors aggregated 1,325,302,505 short tons, valued at $11,829,859,589. These figures do not include the enormous traffic in logs which traffic was dependent only in part upon the Federal improvements.

From these figures it can be shown that the total sum expended on the various harbors on Lake Superior by the United States to date, if imposed as a tonnage tax, would have amounted to 1.07 cents per ton of vessel freight and close to about one-eighth of one per cent. of the money value of the freight.

The reduction in freight rate per ton mile on all Lake Superior freight since 1887 has been 1.12 mills, a reduction which, if applied to the volume of freight carried in United States vessels through the canals at Sault Ste. Marie during the average year 1917-1921, would amount to the cost of all United States improvements on Lake Superior up to January 1, 1922. As wages, fuel, oil and other operating expenses are higher at the present time than in 1887, this decrease in freight rates must be due primarily to the following causes: (a) Federal improvement of the rivers and harbors on the Great Lakes and the connecting waterways, and (b) Improved facilities for loading, unloading and handling vessels.

While it cannot be stated definitely, exactly what proportion of this annual saving of $62,772,360 in freight, as compared with freight charges in 1887, is attributable to river and harbor improvements on Lake Superior alone, yet it is safe to say that the amount thereby saved each year exceeds the aggregate cost of all river and harbor improvements on Lake Superior during the past 55 years.

The saving in vessel freight, however, represents but a small part of the benefit accruing from Government improvements on the Great Lakes; competition has cheapened freight rates by rail; the development and growth of many cities, and of a huge territory have been greatly facilitated by lake commerce; and millions of dollars of capital have found profitable investment in vessels, docks, shipyards, elevators, warehouses, etc., along the shores of the lakes.

The value of the United States craft passing through the canals at Sault Ste. Marie has risen from $2,089,400 in 1887 to

$240,000,000 in 1920, and the safety of this immense fleet and its cargo, valued at more than a billion dollars, has been greatly enhanced by the number of excellent harbors which have been constructed by the United States on Lake Superior.

Taking into consideration all advantages resulting from the improvement of the rivers and harbors of the Great Lakes, and of their connecting waterways, it is doubtful whether any like sum expended by the Government during the same period has brought quicker returns, or has more richly repaid the original investment.

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